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International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems

Sirpa Kleemola and Martin Forsius (eds.)

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ABSTRACT

The Integrated Monitoring Programme (ICP IM) is part of the effect-oriented activities under the 1979 Convention on Long-range Transboundary Air Pollution, which covers the region of the United Nations Economic Commission for Europe (UNECE). The main aim of ICP IM is to provide a framework to observe and understand the complex changes occurring in natural/semi natural ecosystems.

This report summarizes the work carried out by the ICP IM Programme Centre and several collaborating institutes. The emphasis of the report is in the work done during the programme year 2016/2017 including:

- A short summary of previous data assessments
- A status report of the ICP IM activities, content of the IM database, and geographical coverage of the monitoring network
- A report on connections between calculated Critical Load exceedances and observed fluxes and concentrations of nitrogen in runoff
- A report on concentrations of heavy metals in important forest ecosystem compartments
- National Reports on ICP IM activities are presented as annexes.

TIIVISTELMÄ

Yhdennetyn seurannan ohjelma (ICP IM) kuuluu kansainvälisen ilman epäpuhtauksien kaukokulkeutumista koskevan yleissopimuksen ”Convention on Long-range Transboundary Air Pollution” (1979) alaisiin seurantaohjelmiin. Yhdennetyn seurannan ohjelmassa selvitetään kaukokulkeutuvien saasteiden ja muiden ympäristömuutosten vaikutuksia elinympäristöömme. Muutosten seurantaa ja ennusteita muutosten laajuudesta ja nopeudesta tehdään yleensä pienillä metsäisillä valuma-alueilla, mutta verkostoon kuuluu myös muita alueita.

Tämä julkaisu on kooste ohjelmakeskuksen ja yhteistyölaitosten toiminnasta kaudella 2016/2017, joka sisältää:

- Lyhyen yhteenvedon ohjelmassa aiemmin tehdyistä arvioinneista
- Kuvauksen ICP IM ohjelman toiminnasta ja ohjelman seurantaverkosta
- Katsauksen kriittisen typpikuormituksen ylityksien yhteydestä havaittuihin valunnan typen määriin ja pitoisuuksiin
- Katsauksen raskasmetallien pitoisuuksiin metsäisissä ICP IM ekosysteemeissä
- Kuvauksia kansallisesta ICP IM toiminnasta eri maissa liitteenä.

SAMMANDRAG

Programmet för Integrerad övervakning av miljötillståndet (ICP IM) är en del av monitoringstrategin under UNECE:s luftvårdskonvention (LRTAP). Syftet med ICP IM är att utvärdera komplexa miljöförändringar på avrinningsområden.

Rapporten sammanfattar de utvärderingar som gjorts av ICP IM Programme Centre och de samarbetande instituten under programåret 2016/2017. Rapporten innehåller:

- En sammanfattning av programmets nuvarande omfattning och databasens innehåll
- En syntes av tidigare utvärderingar av data från programmet
- En rapport om sambandet mellan kritisk kvävebelastning och observerade flöden och koncentrationer av kväve i avrinningen.
- En rapport om tungmetallkoncentrationer i skogliga ICP IM ekosystem
- Beskrivning av nationella ICP IM aktiviteter.

CONTENTS

ABBREVIATIONS

AMAP	Arctic Monitoring and Assessment Programme
ANC	Acid neutralising capacity
ALTER-Net	A Long-Term Biodiversity, Ecosystem and Awareness Research Network
CCE	Coordination Center for Effects
CL	Critical Load
CNTER	Carbon-nitrogen interactions in forest ecosystems
ECE	Economic Commission for Europe
EMEP	Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe
EU	European Union
EU LIFE	EU's financial instrument supporting environmental and nature conservation projects throughout the EU
Horizon 2020	H2020, EU Research and Innovation programme
ICP	International Cooperative Programme
ICP Forests	International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests
ICP IM	International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems
ICP Materials	International Cooperative Programme on Effects on Materials
ICP M&M	ICP Modelling and Mapping, International Cooperative Programme on Modelling and Mapping of Critical Loads and Levels and Air Pollution Effects, Risks and Trends
ICP Waters	International Cooperative Programme on Assessment and Monitoring Effects of Air Pollution on Rivers and Lakes
ICP Vegetation	International Cooperative Programme on Effects of Air Pollution on Natural Vegetation and Crops
ILTER	International Long Term Ecological Research Network
IM	Integrated Monitoring
JEG	JEG DM, Joint Expert Group on Dynamic Modelling
LRTAP Convention	Convention on Long-range Transboundary Air Pollution
LTER-Europe	European Long-Term Ecosystem Research Network
LTER-Network	Long Term Ecological Research Network
NFP	National Focal Point
TF	Task Force
Task Force on Health	The Joint Task Force on the Health Aspects of Air Pollution
UNECE	United Nations Economic Commission for Europe
WGE	Working Group on Effects

Summary

Background and objectives of ICP IM

Integrated monitoring of ecosystems means physical, chemical and biological measurements over time of different ecosystem compartments simultaneously at the same location. In practice, monitoring is divided into a number of compartmental subprogrammes which are linked by the use of the same parameters (cross-media flux approach) and/or same or close stations (cause-effect approach).

The International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICP IM, www.syke.fi/nature/icpim) is part of the Effects Monitoring Strategy under the Convention on Long-range Transboundary Air Pollution (LRTAP Convention). The main objectives of the ICP IM are:

- To monitor the biological, chemical and physical state of ecosystems (catchments/plots) over time in order to provide an explanation of changes in terms of causative environmental factors, including natural changes, air pollution and climate change, with the aim to provide a scientific basis for emission control.
- To develop and validate models for the simulation of ecosystem responses and use them (a) to estimate responses to actual or predicted changes in pollution stress, and (b) in concert with survey data to make regional assessments.
- To carry out biomonitoring to detect natural changes, in particular to assess effects of air pollutants and climate change.

The full implementation of the ICP IM will allow ecological effects of heavy metals, persistent organic substances and tropospheric ozone to be determined. A primary concern is the provision of scientific and statistically reliable data that can be used in modelling and decision making.

The ICP IM sites (mostly forested catchments) are located in undisturbed areas, such as natural parks or comparable areas. The ICP IM network presently covers forty-five sites from sixteen countries. The international Programme Centre is located at the Finnish Environment Institute in Helsinki. The present status of the monitoring activities is described in detail in Chapter 1 of this report.

A manual detailing the protocols for monitoring each of the necessary physical, chemical and biological parameters is applied throughout the programme (Manual for Integrated Monitoring 1998, and updated web version).

Assessment activities within the ICP IM

Assessment of data collected in the ICP IM framework is carried out at both national and international levels. Key tasks regarding international ICP IM data have been:

- Input-output and proton budgets
- Trend analysis of bulk and throughfall deposition and runoff water chemistry
- Assessment of responses using biological data
- Dynamic modelling and assessment of the effects of different emission/deposition scenarios, including confounding effects of climate change processes
- Assessment of concentrations, pools and fluxes of heavy metals
- Calculation of critical loads for sulphur and nitrogen compounds, and assessment of critical load exceedance, as well as links between critical load exceedance and empirical impact indicators.

Conclusions from international studies using ICP IM data

Input-output and proton budgets, C/N interactions

Ion mass budgets have proved to be useful for evaluating the importance of various biogeochemical processes that regulate the buffering properties in ecosystems. Long-term monitoring of mass balances and ion ratios in catchments/plots can also serve as an early warning system to identify the ecological effects of different anthropogenically derived pollutants, and to verify the effects of emission reductions.

The most recent results from ICP IM studies are available from the study of Vuorenmaa et al. (2017). Site-specific annual input-output budgets were calculated for sulphate (SO_4) and total inorganic nitrogen (TIN = NO_3-N + NH_4-N) for 17 European ICP IM sites in 1990–2012. Temporal trends for input (deposition) and output (runoff water) fluxes and net retention/net release of SO_4 and TIN were also analysed. Large spatial variability in the input and output fluxes of SO_4 and TIN reflects important gradients of air pollution effects in Europe, with the highest deposition and runoff water fluxes in southern Scandinavia, Central and Eastern Europe and the lowest fluxes at more remote sites in northern European regions. A significant decrease in the total (wet + dry) non-marine SO_4 deposition and bulk deposition of TIN was found at 90% and 65% of the sites, respectively. Output fluxes of non-marine SO_4 in runoff decreased significantly at 65% of the sites, indicating positive effects of international emission abatement actions in Europe during the last 25 years. Catchments retained SO_4 in the early and mid-1990s, but this shifted towards a net release in the late 1990s, which may be due to the mobilization of legacy S pools accumulated during times of high atmospheric SO_4 deposition. Despite decreased deposition, TIN output fluxes and retention rates showed a mixed response with both decreasing (9 sites) and increasing (8 sites) trend slopes, but trends were rarely significant. In general, TIN was strongly retained in the catchments not affected by natural disturbances. The long-term annual variation in net releases for SO_4 was explained by variations in runoff and SO_4 concentrations in deposition, while a variation in TIN concentrations in runoff was mostly associated with a variation of the TIN retention rate in catchments. Net losses of SO_4 may lead to a slower recovery of surface waters than those predicted by the decrease in SO_4 deposition. Continued enrichment of N in catchment soils poses a threat to terrestrial biodiversity and may ultimately lead to higher TIN runoff through N saturation or climate change. Continued monitoring and further evaluations of mass balance budgets are thus needed.

Earlier results from ICP IM studies are summarized below.

The first results of input-output and proton budget calculations were presented in the 4th Annual Synoptic Report (ICP IM Programme Centre 1995) and the updated results regarding the effects of N deposition were presented in Forsius et al. (1996). Data from selected ICP IM sites were also included in European studies for evaluating soil organic horizon C/N-ratio as an indicator of nitrate leaching (Dise et al. 1998, MacDonald et al. 2002). Results regarding the calculation of fluxes and trends of S and N compounds were presented in a scientific paper prepared for the Acid Rain Conference, Japan, December 2000 (Forsius et al. 2001). A scientific paper regarding calculations of proton budgets was published in 2005 (Forsius et al. 2005).

The budget calculations showed that there was a large difference between the sites regarding the relative importance of the various processes involved in the transfer of acidity. These differences reflected both the gradients in deposition inputs and the differences in site characteristics. The proton budget calculations showed a clear relationship between the net acidifying effect of nitrogen processes and the amount of N deposition. When the deposition increases also N processes become increasingly important as net sources of acidity.

A critical deposition threshold of about 8–10 kg N ha^{-1} yr^{-1}, indicated by several previous assessments, was confirmed by the input-output calculations with the ICP IM data (Forsius et al. 2001). The output flux of nitrogen was strongly correlated with key ecosystem variables like N deposition, N concentration in organic matter and current year needles, and N flux in litterfall (Forsius et al. 1996). Soil organic horizon C/N-ratio seems to give a reasonable estimate of the annual export flux of N for European forested sites receiving throughfall deposition of N up to about 30 kg N ha^{-1} yr^{-1}. When stratifying data based on C/N ratios less than or equal to 25 and greater than 25, highly significant relationships were observed between N input and nitrate leached (Dise et al. 1998, MacDonald et al. 2002, Gundersen et al. 2006). Such statistical relationships from intensively studied sites can be efficiently used in conjugation with regional monitoring data (e.g. ICP Forests and ICP Waters data) in order to link process level data with regional-scale questions.

An assessment on changes in the retention and release of S and N compounds at the ICP IM sites was prepared for the 21st Annual Report (Vuorenmaa et al. 2012). Updated and revised data were included in the continuation of the work in the 22nd and 23rd Annual Reports (Vuorenmaa et al. 2013, 2014). The relationship between N deposition and organic N loss and the role of organic nitrogen in the total nitrogen output fluxes were derived in Vuorenmaa et al. (2013).

Sulphur budgets calculations indicated a net release of S from many ICP IM sites, indicating that the soils are releasing previously accumulated S. Similar results have been obtained in other recent European plot and catchment studies.

The reduction in deposition of S and N compounds at the ICP IM sites, caused by the "Protocol to Abate Acidification, Eutrophication and Ground-level Ozone" of the LRTAP Convention ("Gothenburg protocol"), was estimated for the year 2010 using transfer matrices and official emissions. Implementation of the protocol will further decrease the deposition of S and N at the ICP IM sites in western and north western parts of Europe, but in more eastern parts the decrease will be smaller (Forsius et al. 2001).

Results from the ICP IM sites were also summarised in an assessment report prepared by the Working Group on Effects of the LRTAP Convention (WGE) (Sliggers & Kakebeeke 2004, Working Group on Effects 2004).

ICP IM contributed to an assessment report on reactive nitrogen (N_r) of the WGE. This report was prepared for submission to the TF on Reactive Nitrogen and other bodies of the LRTAP Convention to show what relevant information has been collected by the ICP programmes under the aegis of the WGE to allow a better understanding of N_r effects in the ECE region. The report contributed relevant information for the revision of the Gothenburg Protocol. A revised Gothenburg Protocol was successfully finalised in 2012.

It should also be recognized that there are important links between N deposition and the sequestration of C in the ecosystems (and thus direct links to climate change processes). These questions were studied in the CNTER-project in which data from both the ICP IM and EU/Intensive Monitoring sites were used (Gundersen et al. 2006). A summary report of the CNTER-results on C/N -interactions and nitrogen effects in European forest ecosystems was prepared for the WGE meeting 2007 (ECE/EB.AIR/WG.1/2007/10).

Trend analysis

Empirical evidence on the development of environmental effects is of central importance for the assessment of success of international emission reduction policy. The study of Vuorenmaa et al. (2017) referred to above, contained results also regarding temporal trends. The next phase of the work on trend assessment will be the evaluation of long-term trends (1990–2015) for deposition and runoff water chemistry and fluxes, and climatic variables at 25 ICP IM sites in Europe that commonly belong also to the LTER-Europe/ILTER networks. The manuscript will be submitted to a special issue in Science of the Total Environment with a working title: "Detecting and explaining natural and anthropogenic changes by making use of large extent, long-term ecological research facilities of the international long-term ecosystem research (ILTER) network".

Earlier work is summarized below.

First results from a trend analysis of monthly ICP IM data on bulk and throughfall deposition as well as runoff water chemistry were presented in Vuorenmaa (1997). ICP IM data on water chemistry were also used for a trend analysis carried out by the ICP Waters and results were presented in the Nine Year Report of that programme (Lükewille et al. 1997).

Calculations on the trends of N and S compounds, base cations and hydrogen ions were made for 22 ICP IM sites with available data across Europe (Forsius et al. 2001). The site-specific trends were calculated for deposition and runoff water fluxes using monthly data and non-parametric methods. Statistically significant downward trends of SO_4, NO_3 and NH_4 bulk deposition (fluxes or concentrations) were observed at 50% of the ICP IM sites. Sites with higher N deposition and lower C/N-ratios clearly showed higher N output fluxes, and the results were consistent with previous observations from European forested ecosystems. Decreasing SO_4 and base cation trends in runoff waters were commonly observed at the ICP IM sites. At some sites in the Nordic countries decreasing NO_3 and H^+ trends (increasing pH) were also observed. The results partly confirmed the effective implementation of emission reduction policy in Europe. However, clear responses were not observed at all sites, showing that recovery at many sensitive sites can be slow and that the response at individual sites may vary greatly.

Data from ICP IM sites were also used in a study of the long-term changes and recovery at nine calibrated catchments in Norway, Sweden and Finland (Moldan et al. 2001, RECOVER: 2010 project). Runoff responses to the decreasing deposition trends were rapid and clear at the nine catchments. Trends at all catchments showed the same general picture as from small lakes in Scandinavia.

It was agreed at the ICP IM Task Force meeting in 2004 that a new trend analysis should be carried out. The preliminary results were presented in Kleemola (2005) and the updated results in the 15th Annual Report (Kleemola et al. 2006). Statistically significant decreases in SO_4 concentrations were observed at a majority of sites in both deposition and runoff/soil water quality. Increases in ANC (acid neutralising capacity) were also commonly observed. For NO_3 the situation was more complex, with fewer decreasing trends in deposition and even some increasing trends in runoff/soil water.

Results from several ICPs and EMEP were used in an assessment report on acidifying pollutants, arctic haze and acidification in the arctic region prepared for the Arctic Monitoring and Assessment Programme (AMAP, Forsius and Nyman 2006, www.amap.no). Sulphate concentrations in air generally showed decreasing trends since the 1990s. In contrast, levels of nitrate aerosol were increasing during the arctic haze season at two stations in the Canadian arctic and Alaska, indicating a decoupling between the trends in sulphur and nitrogen. Chemical monitoring data showed that lakes in the Euro-Arctic Barents region are showing regional scale recovery. Direct effects of sulphur dioxide emissions on trees, dwarf shrubs and epiphytic lichens were observed close to large smelter point sources.

Vuorenmaa et al. (2009, 2016) made the more recent trend evaluations (1993–2006 and 1990–2013, respectively) using ICP IM data. These results confirmed the previously observed regional-scale decreasing trends of SO_4 in deposition and runoff/soil water, and suggested that IM catchments have increasingly responded to the decreases in S emissions and deposition of SO_4 during the last 25 years. Acid-sensitive ICP IM sites in northern Europe also exhibited continuing recovery from acidification. Decreased nitrogen emissions have also resulted in decrease of inorganic N deposition, but to a lesser extent than that of SO_4. Inorganic nitrogen fluxes in runoff were decreasing rather than increasing, but trends were highly variable due to complex processes in terrestrial catchment that are not yet fully understood. Besides, the net release of SO_4 in forested catchments fueled by the mobilization of legacy S pools, accumulated during times of high atmospheric sulphur deposition, may delay the recovery from acidification. The more efficient retention of inorganic N than SO_4 results in generally higher leaching fluxes of SO_4 than those of inorganic N in European forested ecosystems. SO_4 thus remains the dominant source of actual soil acidification despite the generally lower input of SO_4 than inorganic N. Critical load calculations for Europe also indicate exceedances of the N critical loads over large areas. Vuorenmaa et al. (2016) also evaluated the long-term trends for climatic variables (precipitation, runoff water volume and air temperature) at IM sites. Many study sites exhibited long-term seasonal trends with a significant increase in air temperature, precipitation and runoff particularly in spring and autumn, but annual trends were rarely significant. It was concluded that the sulphur and nitrogen problem thus clearly requires continued attention as a European air pollution issue, and further long-term monitoring and trend assessments of different ecosystem compartments and climatic variables are needed to evaluate the effects, not only of emission reduction policies, but also of changing climate.

An assessment on changes in the retention and release of S and N compounds at the ICP IM sites was prepared for the 21st Annual Report (Vuorenmaa et al. 2012). Updated and revised data were included in the continuation of the work in the 22nd and 23rd Annual Reports. The role of organic nitrogen in mass balance budget was derived and trends of S and N in fluxes were analysed (Vuorenmaa et al. 2013, 2014).

Detected responses in biological data

The effect of pollutant deposition on natural vegetation, including both trees and understorey vegetation, is one of the central concerns in the impact assessment and prediction. The most recent ICP IM study on dose-response relationships was published by Dirnböck et al. (2014). This study utilized a new ICP IM database for biological data (see below) and focussed on effects on forest floor vegetation from elevated nitrogen deposition.

In many European countries airborne nitrogen coming from agriculture and fossil fuel burning exceeds critical thresholds and threatens the functioning of ecosystems. One effect is that high levels of nitrogen stimulate the growth of only a few plants which outcompete other, often rare species. As a consequence biodiversity declines. Though this is known to happen in natural and semi-natural grasslands, it has never been shown in forest ecosystems where management is a strong, mostly overriding determinant of biodiversity. Dirnböck et al. (2014) utilized long-term monitoring data from 28 Integrated Monitoring sites to analyse temporal trends in plant species cover and diversity. At sites where nitrogen deposition exceeded the critical load, the cover of forest plant species preferring nutrient-poor soils (oligotrophic species) significantly decreased whereas plant species preferring nutrient-rich soils (eutrophic species) showed – though weak – an opposite trend. These results show that airborne nitrogen has changed the structure and composition of forest floor vegetation in Europe. Plant species diversity did not decrease significantly within the observed period but the majority of newly established species was found to be eutrophic. Hence it was hypothesized that without reducing nitrogen deposition below the critical load forest biodiversity will decline in the future.

Previous work on biological data is summarized below.

The first assessment of vegetation monitoring data at ICP IM sites with regards to N and S deposition was carried out by Liu (1996). Vegetation monitoring was found useful in reflecting the effects of atmospheric deposition and soil water chemistry, especially regarding sulphur and nitrogen. The results suggested that plants respond to N deposition more directly than to S deposition with respect to vegetation indices. De Zwart (1998) carried out an exploratory multivariate statistical gradient analysis of possible causes underlying the aspect of forest damage at ICP IM sites. These results suggested that coniferous defoliation, discolouration and lifespan of needles in the diverse phenomena of forest damage are for respectively 18%, 42% and 55% explained by the combined action of ozone and acidifying sulphur and nitrogen compounds in air.

As a separate exercise, the epiphytic lichen flora of 25 European ICP IM monitoring sites, all situated in areas remote from local air pollution sources, was statistically related to measured levels of SO_2 in air, NH_4^+, NO_3^- and SO_4^{2-} in precipitation, annual bulk precipitation, and annual average temperature (van Herk et al. 2003, de Zwart et al. 2003). It was concluded that long distance transport of nitrogen air pollution is important in determining the occurrence of acidophytic lichen species, and constitutes a threat to natural populations that is strongly underestimated so far.

In 2010, the Task Force meeting decided upon a new reporting format for biological data. The new format was based on primary raw data, and not aggregated mean values as before. All countries were encouraged to re-report old data in the new format. This was successful and as a result, the full potential of the biological data from the ICP Integrated Monitoring network could be utilised to raise and answer research question that the old database could not.

Dynamic modelling and assessment of the effects of emission/deposition scenarios

In a policy-oriented framework, dynamic models are needed to explore the temporal aspect of ecosystem protection and recovery. The critical load concept, used for defining the environmental protection levels, does not reveal the time scales of recovery. Priority in the ICP IM work is given to site-specific modelling. The role of ICP IM is to provide detailed and consistent physical and chemical data and long time-series of observations for key sites against which model performance can be assessed and key uncertainties identified (see Jenkins et al. 2003). ICP IM participates also in the work of the Joint Expert Group on Dynamic Modelling (JEG) of the WGE.

Dynamic vegetation modelling at ICP IM sites has been initiated with contributions from ICP M&M and ICP Forests. The VSD+ model was applied to simulate soil chemistry at more than ten sites in eight countries (Austria, Belgium, Finland, Germany, Italy, Norway, Poland and Serbia). First results have been reported by Holmberg and Dirnböck (2015, 2016).

Dynamic models have also previously been developed and used for the emission/deposition and climate change scenario assessment at several selected ICP IM sites (e.g. Forsius et al. 1997, 1998a, 1998b, Posch et al. 1997, Jenkins et al. 2003, Futter et al. 2008, 2009). These models are flexible and can be adjusted for the assessment of alternative scenarios of policy importance. The modelling studies have shown that the recovery of soil and water quality of the ecosystems is determined by both the amount and the time of implementation of emission reductions. According to the models, the timing of emission reductions determines the state of recovery over a short time scale (up to 30 years). The quicker the target level of reductions is achieved, the more rapidly the surface water and soil status recover. For the long-term response (> 30 years), the magnitude of emission reductions is more important than the timing of the reduction. The model simulations also indicate that N emission controls are very important to enable the maximum recovery in response to S emission reductions. Increased nitrogen leaching has the potential to not only offset the recovery predicted in response to S emission reductions, but further to promote substantial deterioration in pH status of freshwaters and other N pollution problems in some areas of Europe.

Work has also been conducted to predict potential climate change impacts on air pollution related processes at the sites. The large EU-project Euro-limpacs (2004–2009) studied the global change impacts on freshwater ecosystems. The institutes involved in the project used data collected at ICP IM and ICP Waters sites as key datasets for the modelling, time-series and experimental work of the project. A modelling assessment on the global change impacts on acidification recovery was carried out in the project (Wright et al. 2006). The results showed that climate/global change induced changes may clearly have a large impact on future acidification recovery patterns, and need to be addressed if reliable future predictions are wanted (decadal time scale). However, the relative significance of the different scenarios was to a large extent determined by site-specific characteristics. For example, changes in sea-salt deposition were only important at coastal sites and changes in decomposition of organic matter at sites which are already nitrogen saturated.

In response to environmental concerns, the use of biomass energy has become an important mitigation strategy against climate change. A summary report on links between climate change and air pollution effects, based on results of the Euro-limpacs project, was prepared for the WGE meeting 2008 (ECE/EB.AIR/WG.1/2008/10). It was concluded that the increased use of forest harvest residues for biofuel production is predicted to have a significant negative influence on the base cation budgets causing re-acidification at the study catchments. Sustainable forestry management policies would need to consider the combined impact of air pollution and harvesting practices.

Pools and fluxes of heavy metals

The work to assess concentrations, stores and fluxes of heavy metals at ICP IM sites is led by Sweden. Preliminary results on concentrations, fluxes and catchment retention were reported to the Working Group on Effects (document EB.AIR/WG.1/2001/10). The main findings on heavy metals budgets and critical loads at ICP IM sites were presented in Bringmark (2011). Input/output budgets and catchment retention for Cd, Pb and Hg in the years 1997–2011 were determined for 14 ICP IM catchments across Europe (Bringmark et al. 2013). Litterfall plus throughfall was taken as a measure of the total deposition of Pb and Hg (wet + dry) on the basis of evidence suggesting that, for these metals, internal circulation is negligible. The same is not true for Cd. Excluding a few sites with high discharge, between 74 and 94 % of the input, Pb was retained within the catchments; significant Cd retention was also observed. High losses of Pb (>1.4 mg m^{-2} yr^{-1}) and Cd (>0.15 mg m^{-2} yr^{-1}) were observed in two mountainous Central European sites with high water discharge. All other sites had outputs below or equal to 0.36 and 0.06 $mg\,m^{-2}\,yr^{-1}$, respectively, for the two metals. Almost complete retention of Hg, 86–99 % of input, was reported in the Swedish sites. These high levels of metal retention were maintained even in the face of recent dramatic reductions in pollutant loads. In the Progress report on heavy metal trends at ICP IM sites (Åkerblom, S. & Lundin, L. 2015) temporal trends were seen in forest floor with decreasing concentrations for Cd and Pb while Hg did not change. An increase in heavy metal concentrations was also seen in deeper mineral soil horizon indicating a translocation of heavy metals from upper to deeper soil horizons.

In many national studies on ICP IM sites, detailed site-specific budget calculations of heavy metals (including mercury) have improved the scientific understanding of ecosystem processes, retention times and critical thresholds. ICP IM sites are also used for dynamic model development of these compounds.

In this report (Chapter 3) data on Pb, Cd, Hg, Cu and Zn from countries in the ICP IM are presented. These data will be used for establishment of background heavy metal concentrations in forested compartments and risk assessments of heavy metals.

Calculation of critical loads and their exceedance, relationships to effect indicators

Empirical impact indicators of acidification and eutrophication were determined from stream water chemistry and runoff observations at ICP IM catchments (Holmberg et al. 2013). The indicators were compared with exceedances of critical loads of acidification and eutrophication obtained with deposition estimates for the year 2000. Empirical impact indicators agreed well with the calculated exceedances. Annual mean fluxes and concentrations of acid neutralizing capacity (ANC) were negatively correlated with the exceedance of critical loads of acidification. Observed leaching of nitrogen was positively correlated with the exceedances of critical loads (Holmberg et al. 2013). This study was revisited with new data on N concentrations and fluxes (see Chapter 2 of present Annual Report). Data from the ICP IM provide evidence of a connection between modelled critical loads and empirical monitoring results for acidification parameters and nutrient nitrogen.

Planned activities

- Maintenance and development of a central ICP IM database at the Programme Centre.
- Continued assessment of the long-term effects of air pollutants to support the implementation of emission reduction protocols, including:
  - Assessment of trends.
  - Calculation of ecosystem budgets, empirical deposition thresholds and site-specific critical loads.
  - Dynamic modelling and scenario assessment.
  - Comparison of calculated critical load exceedances with observed ecosystem effects.
- Calculation of pools and fluxes of heavy metals at selected sites.
- Assessment of cause-effect relationships for biological data, particularly vegetation.
- Coordination of work and cooperation with other ICPs, particularly regarding dynamic modelling (all ICPs), cause-effect relationships in terrestrial systems (ICP Forests, ICP Vegetation), and surface waters (ICP Waters).

- Participation in the development of the European LTER-network (Long Term Ecological Research network, www.lter-europe.net), and the related EU/H2020-infrastructure project eLTER.
- Cooperation with other external organisations and programmes, particularly the International Long Term Ecological Research network (ILTER, www.ilternet.edu).
- Participation in projects with a global change perspective.

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1 ICP IM activities, monitoring sites and available data

1.1 Review of the ICP IM activities in 2016–2017

Meetings

- ICP IM Programme Manager Martin Forsius and Maria Holmberg participated in the Annual meetings of the LTER-Europe network and the eLTER H2020 project in Riga, Latvia, 15–16 June 2016.
- The Chairman Lars Lundin and Martin Forsius represented ICP IM in the Second Joint Session of the Steering Body to the EMEP and the Working Group on Effects in Geneva, Switzerland, 13–16 September 2016.
- Martin Forsius took part in the International Long-Term Ecological Research (ILTER) 1st Open Science Meeting: Long-Term Ecosystem Research for sustainability under global changes – Findings and challenges of ILTER from local to global scales, organized in the Kruger National Park, South Africa, 9–13 October 2016.
- Maria Holmberg represented ICP IM programme in the Joint Expert Group on Modelling (JEG) meeting 26–28 October 2016 in Sitges, Spain.
- Martin Forsius participated in the AdvanceLTER kick-off meeting in Leipzig, Germany, 1– 2 February 2017.
- Lars Lundin represented ICP IM in the Joint EMEP Steering Body and Working Group on Effects bureaux meeting in Geneva, Switzerland, 20–23 March 2017.
- Martin Forsius participated in the eLTER workshop in Creete, Greece, 27–31 March 2017.
- The twenty-fifth meeting of the Programme Task Force on ICP Integrated Monitoring was organized as a joint 2017 Task Force Meeting of ICP Waters and ICP Integrated Monitoring in Uppsala, Sweden from May 9 to May 11, 2017.

Projects, data issues

After December 1st 2016 the National Focal Points (NFPs) reported their 2015 results to the ICP IM Programme Centre. The Programme Centre carried out standard check-up of the results and incorporated them into the IM database.

Scientific work in priority topics

- The Programme Centre prepared the ICP IM contribution to the Joint Report 2016 of the ICPs, TF health and Joint Expert Group on Dynamic Modelling for the WGE (ECE/EB.AIR/GE.1/2016/3 - ECE/EB.AIR/WG.1/2016/3).

- Scientific paper: Long-term sulphate and inorganic nitrogen mass balance budgets in European ICP Integrated Monitoring catchments (1990–2012) (J. Vuorenmaa et al.) was finalized and was published in Ecological Indicators.
- Report on connections between calculated CL exceedances and observed impacts of nitrogen (Maria Holmberg, Jussi Vuorenmaa et al.) is included as chapter 'Relationship between critical load exceedances and empirical impact indicators at IM sites – update 2017' in the present Annual Report.
- Report on concentrations of heavy metals in important forest ecosystem compartments (Staffan Åkerblom & Lars Lundin) is presented in this Annual Report.
- ICP IM has contributed to the Joint Report on mercury in the aquatic environment (Joint report together with ICP Waters).
- ICP IM participates in a joint coordinated exercise on dynamic modelling together with other ICPs (Joint Expert Group on Dynamic Modelling, JEG DM). Priority in the ICP IM work is given to site-specific modelling activities and development/testing of new methodologies for assessing the connections between air pollution and climate change.

1.2
Activities and tasks planned for 2018–2019

Activities/tasks related to the programme's present objectives, carried out in close collaboration with other ICPs/ Task Forces

According to the ICP IM workplan, ICP IM will produce the following reports:

2018: Scientific paper on long-term trends in atmospheric deposition and runoff water chemistry of S and N compounds at ICP IM catchments in relation to changes in emissions and hydro meteorological conditions

2018: Scientific paper on dynamic modelling on the impacts of future deposition scenarios on soil and water conditions in ICP IM catchments

2019: Report on dynamic modelling on the impacts of deposition and climate change scenarios on ground vegetation

2019: Scientific paper on the relationship between critical load exceedances and empirical ecosystem impact indicators

Other activities

- Maintenance and development of central ICP IM database at the Programme Centre
- Arrangement of the 26th Task Force meeting (2018)
- Preparation of the 27th ICP IM Annual Report (2018)
- Preparation of the ICP IM contribution to assessment reports of the WGE
- Participation in meetings of the WGE, other ICPs and the JEG DM

Activities/tasks aimed at further development of the programme

- Participation in the development of the European LTER-network (Long Term Ecological Research network, www.lter-europe.net), and the EU/H2020 eLTER-project.
- Participation in the activities of other external organisations, particularly the International Long Term Ecological Research Network (ILTER, www.ilternet.edu)

1.3

Published reports and articles 2016–2017

Evaluations of international ICP IM data and related publications

Kleemola, S. & Forsius, M. (Eds.) 2016. 25th Annual Report 2016. Convention on Long-range Transboundary Air Pollution, ICP Integrated Monitoring. Reports of the Finnish Environment Institute 29/2016, Finnish Environment Institute, Helsinki. 69 p. http://hdl.handle.net/10138/166236

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Evaluations of national ICP IM data and publications of ICP IM representatives

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Kopáček, J., Hejzlar, J., Krám,,P., Oulehle, F., Posch, M. 2016. Effect of industrial dust on precipitation chemistry in the Czech Republic (Central Europe) from 1850–2013. Water Research 103: 30–37.

Krám, P., Čuřík, J., Veselovský, F., Myška, O., Hruška, J., Štědrá, V., Jarchovský, T., Buss, H.L., Chuman, T. 2017. Hydrochemical fluxes and bedrock chemistry in three contrasting catchments underlain by felsic, mafic and ultramafic rocks. Procedia Earth and Planetary Sciences 17: 538–541.

Olin, M., Tiainen, J., Kurkilahti, M., Rask, M. & Lehtonen, H. 2016. An evaluation of gillnet CPUE as an index of perch density in small forest lakes. Fisheries Research 173: 20–25.

Oulehle, F., Chuman, T., Hruška, J., Krám, P., McDowell, W.H., Myška, O., Navrátil, T., Tesař, M. 2017. Recovery from acidification alters concentrations and fluxes of solutes from Czech catchments. Biogeochemistry 132: 251–272.

Oulehle, F., Kopáček, J., Chuman, T., Černohous, V., Hůnová, I., Hruška, J., Krám, P., Lachmanová, Z., Navrátil, T., Štěpánek, P., Tesař, M., Evans, C.D. 2016. Predicting sulphur and nitrogen deposition using a simple statistical method. Atmospheric Environment 140: 456–468.

Rousseva, S., Kercheva, M., Shishkov, T., Lair, G.J., Nikolaidis, N., Moraetis, D., Krám, P., Bernasconi, S., Blum, W., Menon, M., Banwart, S.A. 2017. Soil water characteristics of European SoilTrEC Critical Zone Observatories. Advances in Agronomy 142: 29–72.

Štědrá, V., Jarchovský, T., Krám, P. 2016. Lithium-rich granite in the Lysina-V1 borehole in the southern part of the Slavkov Forest, western Bohemia (in Czech, English abstract and captions). Geoscience Research Reports 49: 137–142.

Thom, D., Rammer, W., Dirnböck, T., Müller, J., Kobler, J., Katzensteiner, K., Helm, N. & Seidl, R. 2017. The impacts of climate change and disturbance on spatio-temporal trajectories of biodiversity in a temperate forest landscape. Journal of Applied Ecology, 54: 28–38.

1.4
Monitoring sites and data

The following countries have continued data submission to the ICP IM data base during the period 2012–2016: Austria, Belarus, the Czech Republic, Estonia, Finland, Germany, Ireland, Italy, Lithuania, Norway, Poland, the Russian Federation, Spain, Sweden, Switzerland and Ukraine. Poland rejoined the network with two sites and will add more sites later.

The number of sites with on-going data submission for at least part of the data years 2011–2015 is 45 from sixteen countries. Sites from Canada, Latvia and United Kingdom only contain older data.

An overview of the data reported internationally to the ICP IM database is given in Table 1.1. Additional earlier reported data are available from sites outside those presented in Table 1.1. and Fig. 1.1. Locations of the ICP IM monitoring sites are shown in Fig. 1.1.

Table 1.1. Internationally reported data from ICP IM sites (- subprogramme not possible to carry out, * or forest health parameters in former Forest stands/Trees).

AREA	SUBPROGRAMME																							
	AM	AC	PC	MC	TF	SF	SC	SW	GW	RW	LC	FC	LF	RB	LB	FD	VG	BI	VS	EP	AL	MB	BB	BV
	meteorology	air chemistry	precipitation chemistry	moss chemistry	throughfall	stemflow	soil chemistry	soil water chemistry	groundwater chemistry	runoff water chemistry	lake water chemistry	foliage chemistry	litterfall	hydrobiology of streams	hydrobiology of lakes	forest damage	vegetation	bioelements	vegetation structure	trunk epiphytes	aerial green algae	microbial decomposition	bird inventory	vegetation inventory
AT01	95-15	95-15	93-15		93-15	99-04		93-15		95-15	-	92-11	93-15				93			93-98				
BY02	89-15	89-15	89-15				95-98			95-15														
CH02		15	15							15	15													
CZ01	89-15	89-15	89-15	89	89-15			07-15	08-15	89-15	-			07	-									
CZ02	67-16	93-96	90-15		91-15		93	90-15	89-15	89-15	91-15	94	08	07	11		15	94			14-15		10	
DE01	90-15	90-15	90-15	90	90-15	90-05	90-11	90-15	88-15	90-15	-	90-15	90-15		-	90-14	90-08		00	92-95		94-15	91-02	90-95
DE02	67-15	98-15	98-15		98-15	04-15	04-10	98-15	98-15		98-15	06-15	04-15				04-06							
EE01	95-15	94-15	94-15	94-15	94-15	94-15	94-15	94-15	95-96	-	-	94-15	94-15	-	-	94-15	94-97			94-04		94-15		94
EE02	94-15	98-15	94-15	94-12	94-15	94-15	94-15	95-15	95-14	94-15	96	94-15	94-15			96-15	96-12	12		94-15	94-15	96-15	98-14	
ES02	08-15	08-15	07-15		07-15	08-15	10-15	07-15		07-15		08-15	08-15			07-12	07		07					
FI01	88-15	94-15	88-15	88-96	89-15	89-99	88-89	89-01		88-15	87-15	88-01	90-97		90-93	88-91	88-09			88-97		90	87-89	87
FI03	88-15	93-00	88-15	89-96	89-15	89-99	88	89-01		88-15	87-15	88-01	90-97		90	88-91	90-09			90-97		90-91	87-89	
FI04	88-15	89-15	88-15	89-96	89-10	89-97	89	89-01		88-05	86-12	89-01	90-97			89-91	89-09			89-98		90-91	87-89	
FI05	88-15		88-15	91-96	89-97	89-97	88	89-96		89-15	87-15	88-01	90-97			88-91	89-09			89-97		90-91	88-89	
FI06			14-15																				88-89	
IE01			91-11		91-11	92-97		91-11			-	91-96	91-98	-	-									
IT01	90-15	93-15	93-14		93-13	93-13	93-11	93-13		00-13	-	93-10	00	-	-	92-13	09		05-09	92		93-11		
IT02	77-13	93	93-14		93-13	93-13	93-10	93-13		-	-	93-01	00	-	-	92-13				92		93-11		
IT03	92-08	93-13	92-13		94-13	94-00	93-95	95-07		01-13	-	93-05	94	-	-	93-09	95-09		99-09	92				
IT05	97-08	97-15	97-15		97-15	97-15	95	02-08		-	-	97-05		-	-	97-09	09		99-09					
IT06	99-08	97-15	97-15		97-15	97-15	95			-	-	97-05		-	-	97-09	09		99-09					
IT07	97-08	97-15	97-15		97-15	97-00	95			98-13	-	97-05		-	-	97-09	09		99-09					
IT09	97-08	97-15	97-15		97-15	97-00	95	02-08		97-14	-	97-05		-	-	97-09	09		99-09					
IT10	97-08	00-15	97-15		97-15		95	05-07		-	-	97-05		-	-	97-09	09		99-09					
IT11		97-11	97-12		97-12		95			-	-	97-05		-	-	97-09	09		99-09					
IT12	97-01	97-15	97-15		97-15	97-00	95			-	-	97-05		-	-	97-09	09		99-09					
IT13	97-08	97-15	09-15		09-15		95			-	-	97-05		-	-	97-09			99-08					
LT01	93-13	93-15	93-15	93-10	93-15		93-05	94-12	93-12	93-14		06-16	99-16	12		00-13	93-15		02-15	93-16	93-16			93
LT03	90-13	95-15	95-15	06-10	95-15		94-05	95-12	95-12	95-14		06-16	99-16	95-12		00-13	94-15		02-15	94-16	94-16			94
NO01	87-15	87-15	87-15	92	89-15		86	89-15	87-88	87-15	-	86			-	91-03	86-13			86				
NO02	87-91	87-15	87-15	88	89-11		89	89-09		87-15	-	89			-	92-03	89-09							
NO03		87-97	77-15							87-15														
PL06	94-15		94-15		96-15					94-15														
PL10	94-15		94-15		02-15					94-15														
RU03	89-94	89-15	89-98																					
RU04	89-06	89-15	89-98	90										93-99		93-14	93-02			93		94-96		
RU12	93-94	93-15	93-94																					
RU13	93	93-94	93													09-15								
RU14	94	94-15	94-98																					
RU16				89-90			89	89	89						93-99	93-15	91-94			89-94	93	94-95		91
SE04	87-15	88-15	87-15	95	87-15		95	87-15	79-15	87-15	-	99-15	96-15		-	97-01	95-13	91-15	91-15	96-11	92-15	95-15		
SE14	96-15	96-15	96-15	95	96-15			95-15	96-15	96-15	-	99-15	95-15		-	97-01	82-13	96-11	06-11	97-12	97-15	95-15		
SE15	97-15	96-15	96-15		96-15		97	95-15	97-15	96-15	-	97-15	95-15		-	98-01	96-14	98-13	98-13	98-13	97-15	95-15		
SE16	99-15	99-15	99-15		99-15			00-15	00-15	99-15		99-15	00-15			00-01	99-15	99-14	99-14	00-15	00-15	00-15		
UA01	12-13	12-13																						

Figure 1.1. Geographical location of ICP IM sites.

1.5

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2 Relationship between critical load exceedances and empirical impact indicators at IM sites - Update 2017

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2.1
Introduction

Critical loads for eutrophication and their exceedances were determined for a selection of sites (Table 2.1) in the Integrated Monitoring programme. The exceedances ($ExCL_{nut}N$) were calculated as differences between the level of total N deposition (Ntot $= NO_3 + NH_4$) and the mass balance critical loads of nitrogen ($CL_{nut}N$). Concentrations and fluxes of total inorganic nitrogen (TIN $= NO_3^- + NH_4^+$) in runoff were determined for the same sites, as empirical indicators of the level of eutrophication. The deposition and the empirical indicators were previously determined for the year 2000 (Holmberg et al. 2013). Here we report an update using modelled deposition values for the year 2010 and empirical indicator values based on water quality observations for the years 2013-2015. For most sites, there was an improvement visible as a shift towards less exceedance and lower concentrations of TIN in runoff. At the majority of the sites both the input and the output flux of TIN decreased between the two observation periods 2000–2002 and 2013–2015.

2.2

N in deposition

The input of N from (long-range) transport of air pollutants is needed for an assessment of the exceedance of critical loads. The N input can be estimated by modelled deposition to each site or, alternatively, by the flux of N calculated from the observed concentration of TIN in bulk precipitation and the amount of precipitation. The modelled total deposition of N to each site was compared to the observed TIN flux separately for the periods 2000–2002 and 2013–2015 (Fig. 2.1). For most sites, the modelled N deposition was higher than the observed flux in bulk precipitation. This was expected, as the modelled values represent the total input of both dry and wet deposition to the site.

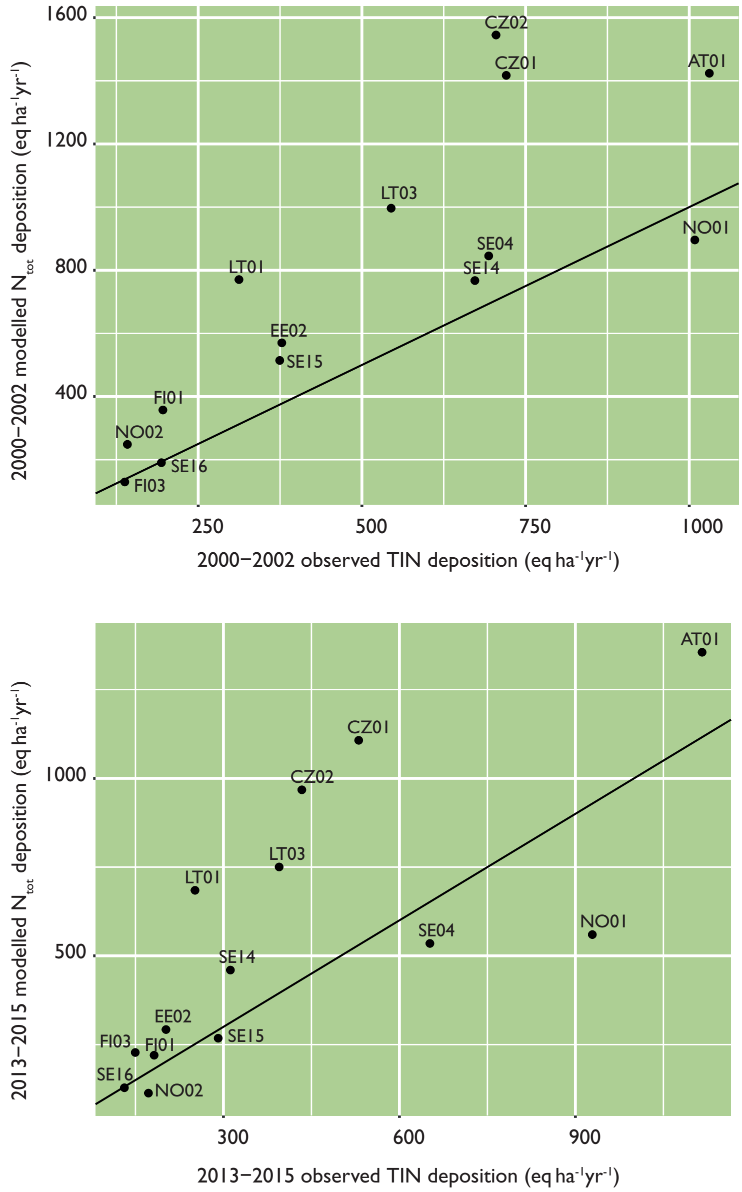

Figure 2.1. Comparison of modelled to observed N input to the sites. Period 2000–2002 in upper panel, period 2013–2015 in lower panel. The line is drawn at slope 1:1.

The change over time in the modelled and the observed bulk deposition were compared by plotting each separately with the values for the previous period on the x-axis and the latter period on the y-axis (Fig. 2.2). Both the observed and the modelled estimates for N input to the sites have decreased with time for almost all sites. For AT01, FI03 and NO02, the observed input flux of N was slightly higher in the latter period (Fig. 2.2a). Only FI03 received higher modelled deposition in the latter period than in the former one (Fig. 2.2b).

A long-term trend assessment at IM sites has shown that decreased nitrogen emissions have resulted in a decrease of inorganic N deposition at the majority of sites between 1990 and 2013 (Vuorenmaa et al. 2016). IM sites showed dominantly negative trend slopes in NO_3 and NH_4 concentrations in bulk and throughfall deposition (ca 90% of the sites). Bulk deposition of NO_3 and NH_4 decreased significantly at 70–80% (concentrations) and 40% (fluxes) of the sites, while concentrations and fluxes in throughfall decreased at 50% and 20–40% of the sites, respectively.

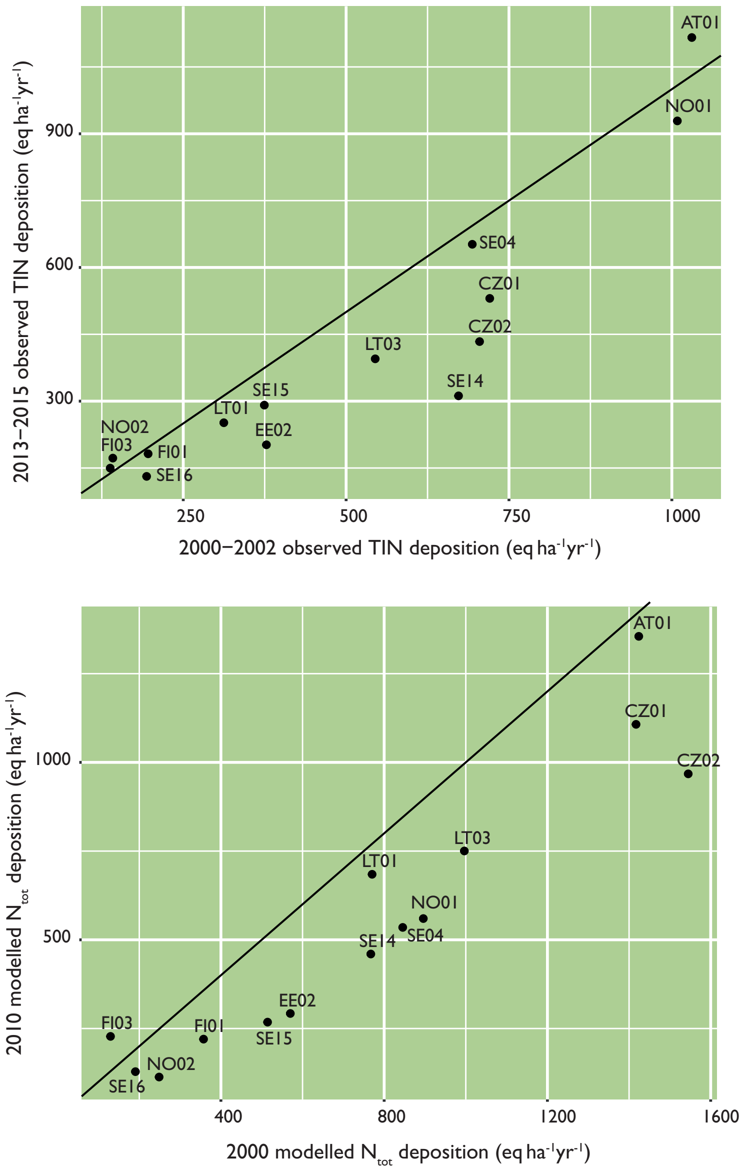

Figure 2.2. Comparison of N input to the sites for the period 2013–2015 (y-axis) versus period 2000–2002 (x-axis). Observed values in upper panel (a), modelled values in lower panel (b). The line is drawn at slope 1:1.

2.3

N in runoff

We illustrate the differences between the two observation periods (2000–2002, 2013–2015) by plotting the observed concentrations and fluxes of TIN in runoff (Fig. 2.3) with the values for the former period on the x-axis and those for the latter period on the y-axis. The concentrations of TIN have decreased at all sites except two (AT01, SE04, Fig. 2.3a); also the output fluxes of TIN have decreased at most sites (Fig. 2.3b), while they have increased at four sites (AT01, FI03, LT01, SE04 and SE14).

It should be noted, however, that the differences presented here also reflect variations in meteorological and hydrological conditions and altered biogeochemical N cycles within the catchments by well-known forest disturbance regimes. Detailed analysis of temporal trends for input and output fluxes of TIN are available in Vuorenmaa et al. (2016, 2017).

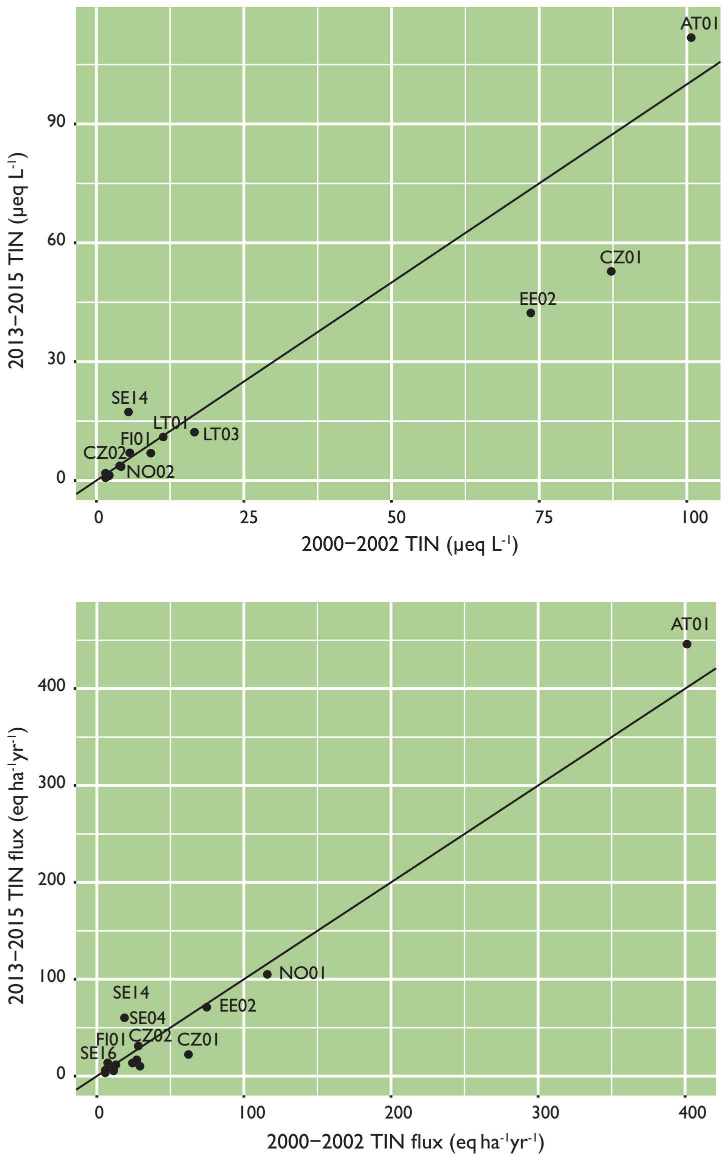

Figure 2.3. Observed concentration (upper, a) and flux (lower, b) of TIN in runoff, averages for period 2013-2015 (y-axis) compared to those for 2000-2002 (x-axis). The line is drawn at slope 1:1.

To illustrate changes in the retention of N over time, the observed TIN concentrations in runoff were plotted against the observed TIN flux as calculated from the TIN concentration in bulk precipitation (Fig. 2.4). In the latter period, the sites EE02 and CZ01 move closer to the rest of the sites and AT01 remains singularly high in output concentration (Fig. 2.4b).

The previous trend assessment (1990–2013) for the IM sites (Vuorenmaa et al. 2016) showed a mixed response with both decreasing and increasing trend slopes for NO_3 concentrations and fluxes in runoff, but trends for concentrations and fluxes were increasing rather than decreasing. Significant decreases of NO_3 fluxes in runoff were detected at four sites, while NO_3 flux increased significantly at five sites, but increasing trends were likely not linked to direct N deposition effects. Thus, the trends for output fluxes of NO_3 are still highly variable, indicating that surface water-watershed nitrogen dynamics are inherently complex as nitrogen is strongly affected by biological processes, and nitrate concentrations in surface waters may highly fluctuate with season and spatially across ecosystems. Moreover, the short and long-term variations in climate may mask long-term trends caused by N deposition.

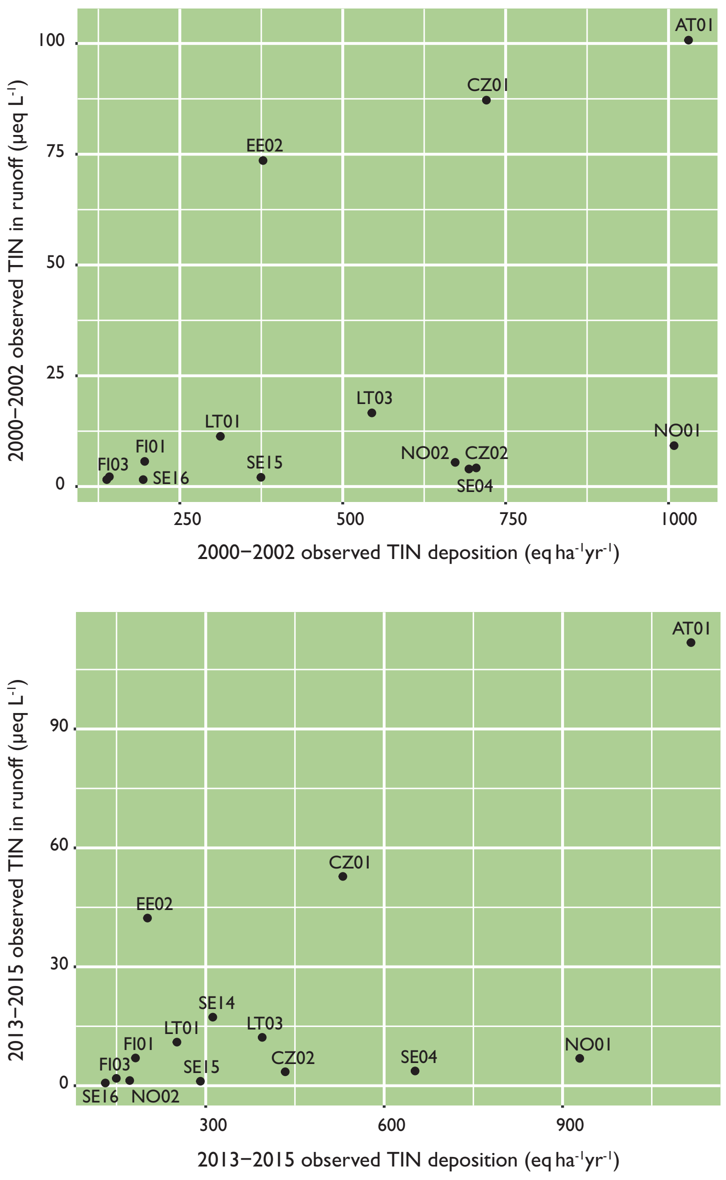

Figure 2.4. The observed concentration of TIN in runoff (y-axis) versus the observed input flux of TIN (x-axis) as calculated from the concentration of TIN in bulk precipitation and the amount of precipitation. Period 2000–2002 in upper panel (a), period 2013–2015 in lower panel (b).

2.4

Exceedance of critical loads of eutrophication

The increased risk of harmful effects is quantified by the exceedance of a critical load. For nutrient N critical loads, the exceedance is defined as the difference between the total N deposition and the critical load value. Negative exceedance values (for sites where the critical loads are not exceeded) are included in graphs in order to show the difference between deposition and critical load value for all cases.

To calculate the exceedance, we use modelled total (wet and dry) deposition to the sites. The modelled total deposition Ntot (and the exceedance of the critical load) has decreased at all sites except FI03 (Fig. 2.2b). For most sites, there was a shift towards less exceedance and lower concentrations of TIN in runoff (Fig. 2.5). At four sites (AT01, LT01, SE04 and SE14), the input flux decreased while the output flux increased. At all other sites both the input and the output decreased (Fig. 2.6).

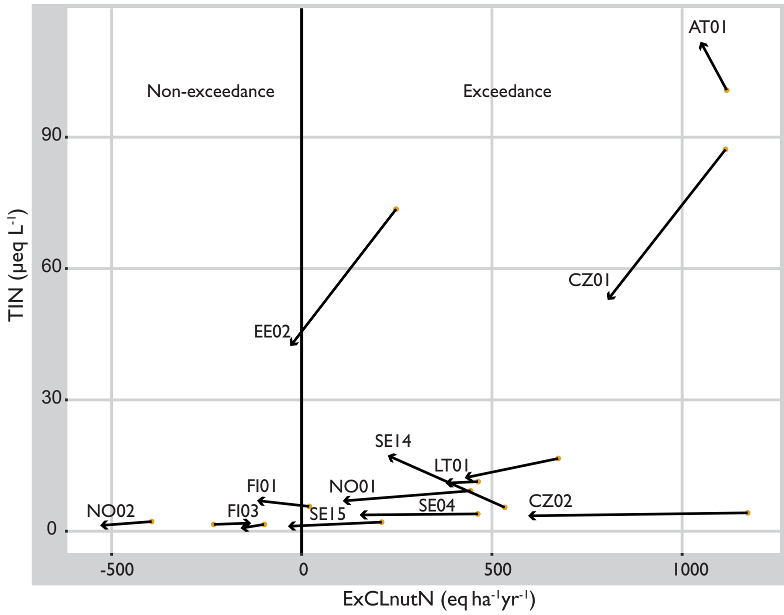

Figure 2.5. The observed concentration of TIN in runoff (y-axis) versus the calculated exceedance of critical loads of nutrient N (x-axis), using modelled deposition values. The arrows begin at the locations of the data points for the period 2000-2002 and end at the locations of the data points for the period 2013–2015.

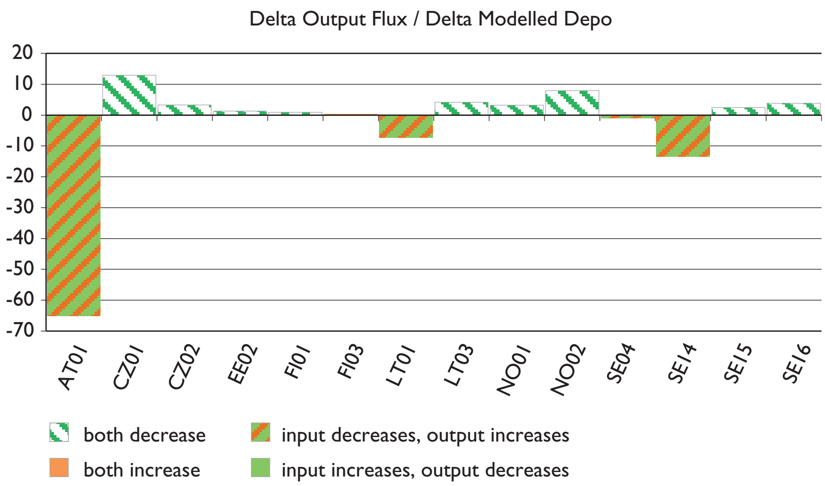

Figure 2.6. Comparison of changes in TIN-N flux in runoff, relative to the change in deposition. Changes calculated as differences between the values for 2013–2015 and those for 2000–2002. Relative changes (%) as change in flux divided by change in modelled deposition. This comparison reflects also differences in meteorological and hydrological conditions and altered biogeochemical N cycles within the catchments by well-known forest disturbance regimes for the two periods.

Table 2.1. N concentrations, fluxes and exceedances of critical loads at ICP IM sites.

			2000-2002	2000-2002	2000	2000	2013-2015	2013-2015	2010	2010
Country	IM Site code	Site	TIN conc. (μeq L^{-1})	TIN flux (eq ha^{-1} yr^{-1})	Ntot dep. (eq ha^{-1} yr^{-1}) (modelled)	ExCLnutN (eq ha^{-1} yr^{-1})	TIN conc. (μeq L^{-1})	TIN flux (eq ha^{-1} yr^{-1})	Ntot dep. (eq ha^{-1} yr^{-1}) (modelled)	ExCLnutN (eq ha^{-1} yr^{-1})
Austria	AT01	Zöbelboden IP1	100.8	401.3	1424	1117	111.8	446	1355	1049
Czech Republic	CZ01	Anenske Povodi	87.2	62.3	1417	1114	52.8	22.3	1107	804
	CZ02	Lysina	4.2	29.3	1545	1172	3.52	10.2	968	595
Estonia	EE02	Vilsandi	45.4	74.7	570	248	42.3	71.1	292	-30
Finland	FI01	Valkea-Kotinen	5.7	12.9	357	20	7	11.7	220	-117
	FI03	Hietajärvi	1.6	5.8	130	-231	1.86	6.2	228	-133
Lithuania	LT01	Aukstaitija	11.3	7.4	770	464	11	13.7	685	378
	LT03	Zemaitija	16.6	27.1	997	674	12.2	16.8	750	428
Norway	NO01	Birkenes	9.2	115.9	896	444	6.91	105	560	108
	NO02	Kårvatn	2.2	24.2	249	-394	1.31	13.5	113	-530
Sweden	SE04	Gårdsjön	3.7	28.2	845	463	3.72	31.1	535	152
	SE14	Aneboda	5.5	18.8	767	534	17.3	60.2	460	226
	SE15	Kindla	2.0	11.4	514	210	1.13	5.4	268	-36
	SE16	Gammtratten	1.6	5.7	191	-99	0.69	3.3	128	-161

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3 Report on concentrations of heavy metals in important forest ecosystem compartments

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3.1

Introduction

Long-range atmospheric transport and deposition of heavy metals (HM) have increased the exposure to forest ecosystems. Exposure of HM to terrestrial ecosystems may cause ecotoxicological effects on soil organisms and plants but also on aquatic organisms in runoff to surface water. Uptake of HM in aquatic food chains may result in health effects on animals and humans that use fish as a source of food. Under the Convention on Long-range Transboundary Air Pollution (UNECE CLRTAP), reductions of anthropogenic emissions of HM to the atmosphere were agreed in 1998 under the Aarhus protocol on HM with priority on mercury (Hg), lead (Pb) and cadmium (Cd) (UNECE 2003). In addition to the prioritized HMs, reporting of data on copper (Cu) and Zink (Zn) have also been encouraged.

Measures to reduce HM emissions are followed up in forested catchments under the International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICP IM) and data have been reported on HM in subprogrammes for forest compartments of precipitation chemistry (PC), througfall (TF), litterfall (LF), soil chemistry (SC), and runoff water (RW). Interception of precipitation with the forest canopy commonly causes accumulation of HM in precipitation that thus increase HM concentrations in TF compared to that found in PC (Nieminen et al. 1999). Catchment budgets show ongoing accumulation of HM and the release (RW) seldom exceeds input (PC + TF + LF) (Aastrup et al. 1991, Ukonmaanaho et al. 2001, Grigal 2002, Bringmark et al. 2013). The build-up of HM in soil stores, reflected in SC, are to a large degree dependent on long-term and long-range atmospheric transport with consecutive deposition (Lundin et al. 2001, Steinnes & Friedland 2006). Spatial variation of HM levels across member states has been included within ICP IM to get an estimate on the variation of HM between countries. Temporal trends in Cd, Pb and Hg have shown decreasing trends over years with the highest concentrations found before 2000 (Åkerblom et al. 2015).

Reported data from compartmental subprogrammes (PC, TF, LF, SC and RW) at European ICP IM sites were summarized to provide typical HM concentrations from each compartment. This report presents country specific concentrations for HM that are considered within the work of the CLRTAP. Spatial coverage of available data from compartments within ICP IM countries will be used to make further assessments of background HM concentrations and environmental risk.

3.2

Material and methods

Data reported to the ICP IM Programme Centre at the Finnish Environment Institute (SYKE, Helsinki, Finland) were used for the analysis. Heavy metal (Cd, Pb, Hg, Cu and Zn) concentrations for forest compartments SC, PC, TF, LF and RW were evaluated at ICP IM sites across Europe. Data reported as being below the detection limit as well as zero-values were excluded from the data presentation. SC heavy metal concentrations were determined in four soil layers, i.e. organic layer+litter (OH-litter), 0–10 cm depth, 10–30 cm depth, 30–200 cm depth. Often the distributions of concentrations were severely skewed and median concentrations from ICP IM sites within each country were used in the presentation of HM data.

3.3

Results and discussion

3.3.1

Cadmium

Reported PC data show large variation in Cd concentrations between the countries with lowest (0.02 µg L^{-1}) values in Norway and (0.03 µg L^{-1}) in Finland and Germany and highest in Belarus (1.00 µg L^{-1}) (Table 3.1). Even though Finland had among the lowest Cd concentrations in PC as well as RW (0.02 µg L^{-1}) it held the highest Cd concentrations in TF (1.00 µg L^{-1}) among all countries. Portugal had an extremely high Cd concentration in RW (21 µg L^{-1}) even though this is based on a limited number of observations (n=2) and cover data from only 1 year (1999). Cd concentrations in LF vary between 0.07 mg kg^{-1} (Spain) and 0.36 mg kg^{-1}(The Netherlands).

Table 3.1. Cadmium concentrations (median (n)) and years with data from subprogrammes within ICP IM sites in member states of the UNECE CLRTAP.

Cadmium (Cd)													
	Median (n)								Temporal coverage				
	Subprogramme												
	PC	TF	RW	LF	SC (soil depth cm)				PC	TF	RW	LF	SC
					OH-litter	0–10	10–30	30–200					
	µg L^{-1}			mg kg^{-1}					between years				
Country													
Austria	0.20 (201)	0.11 (101)	0.15 (16)	0.10 (166)					1993–2012	1993–2010	1995–2006	1993–2009	
Belarus	1.00 (105)		1.00 (96)		0.62 (7)				1998–2005				1995–1998
Czech Republic	0.09 (706)	0.12 (741)	0.19 (615)						1989–2013	1989–2015	1989–2013	2008–2008	
Estonia	0.07 (181)	0.13 (203)		0.10 (121)	0.18 (1)	2.14 (4)	0.07 (4)	0.12 (12)	1996–2013	1998–2015		1994–2015	1994–2010
Finland	0.03 (1165)	1.00 (477)	0.02 (929)	0.27 (185)	0.74 (9)	1.46 (16)	1.42 (7)		1993–2012	1992–1999	1988–2013	1904–1997	1988–1989
Germany	0.03 (68)			0.12 (324)	0.52 (12)	0.08 (15)	0.09 (4)	0.05 (6)	2004–2009			1904–2015	1988–2010
Italy	0.30 (1)			0.14 (2)	0.28 (22)	0.15 (24)	0.12 (14)	0.09 (22)	2005–2010			1994–1994	1995–2011
Latvia	0.10 (628)	0.14 (338)	0.03 (157)	0.26 (42)	0.43 (15)	0.03 (13)	0.02 (7)	0.02 (29)	1994–2009	1994–2009	1996–2009	1994–2008	1994–2003
Lithuania			0.04 (120)	0.16 (127)	0.19 (9)	0.06 (19)	0.11 (8)	0.12 (27)			2003–2012	1999–2015	1993–2005
Norway	0.02 (476)				1.3 (2)				1992–2013				1986–1989
Poland	0.25 (58)	0.25 (100)	0.3 (3)		3.12 (9)	0.04 (6)	0.49 (2)	1.29 (8)	1993–1996	1993–1996			1988–1991
Portugal	0.43 (24)		21 (2)						1994–2001		1999–1999		
Russia	0.39 (123)	0.20 (23)							1992–1997	1993–1997			1989–1993
Spain	0.08 (50)	0.08 (56)	0.08 (55)	0.07 (14)		0.08 (4)	0.03 (2)	0.02 (4)	2007–2012	2007–2015	2007–2012	2008–2015	2010–2010
Sweden	0.04 (264)	0.04 (186)	0.03 (517)	0.22 (152)	0.55 (8)	0.07 (1)	0.10 (3)	0.05 (2)	1995–2012	1995–2012	1996–2013	1995–2015	1984–1997
Switzerland													
The Netherlands	0.11 (228)	0.06 (75)		0.36 (6)			0.18 (2)		1984–1999	1993–1999		1993–1998	1993–1997
United Kingdom	0.13 (114)	0.10 (38)							1988–1997	1988–1991			

Within the SC data the OH-litter layer contains the highest concentrations of Cd (0.18–3.12 mg kg^{-1}) compared to lower mineral soil layers at 0–10 cm (0.03–2.14 mg kg^{-1}), 10–30 cm (0.02–1.42 mg kg^{-1}) indicating accumulation of Cd in the upper organic rich layer. The deepest soil horizon (30–200 cm) had commonly the lowest Cd concentrations and varied between 0.02 mg kg^{-1} and 0.12 mg kg^{-1}, even though Poland had an extreme Cd concentration of 1.29 mg kg^{-1}.

3.3.2 Lead (Pb)

Lead concentrations in PC varied between 0.2 (Spain) and 66 (Switzerland) µg L^{-1} (Table 3.2). The high Cd concentrations in PC from Switzerland were reported from 1992–1993 and cover only 4 sampling occasions. Pb concentrations in PC >2 µg L^{-1} (Poland, The Netherlands, United Kingdom, and Russia) were all reported before 2000. Reported Pb concentrations in PC after 2000 varied between 0.2 (Spain) and 1.9 (Czech Republic) µg L^{-1}. The highest median Pb concentrations in TF were also reported from Switzerland (47 µg L^{-1}) from 5 sampling occasions between 1992–1993. Pb concentrations in TF (0.2–12 µg L^{-1} (Switzerland 47 µg L^{-1})) were higher compared to PC even though PC from Russia (4 µg L^{-1}) exceeds Pb concentrations in TF (1 µg L^{-1}). The highest Pb concentrations were found in Czech Republic (1.3 µg L^{-1}) and the lowest were found in Spain (0.2 µg L^{-1}). Median Pb concentrations in RW are commonly lower compared to concentrations found in both PC and TF. Pb concentrations in LF vary between 0.7 mg kg^{-1} (Estonia and Spain) and 4.7 mg kg^{-1} (Italy). In the deepest soil horizon the Pb concentrations are commonly lowest and vary between 3 and 23 mg kg^{-1}. The OH-litter layer had higher Pb concentrations and varied between 12 mg kg^{-1} (Latvia) and 84 mg kg^{-1} (Sweden) compared with mineral soil layers at 0–10 cm (7–56 mg kg^{-1}) and 10–30 cm (3–46 mg kg^{-1}). The deepest soil layer (30–200 cm) contains the lowest Pb concentrations (3–23 mg kg^{-1}).

Table 3.2. Lead concentrations (median (n)) and years with data from subprogrammes within ICP IM sites in member states.

Lead (Pb)													
	Median (n)								Temporal coverage				
	Subprogramme												
	PC	TF	RW	LF	SC (soil depth cm)				PC	TF	RW	LF	SC
					OH-litter	0–10	10–30	30–200					
	µg L^{-1}			mg kg^{-1}					between years				
Country													
Austria	1.4 (224)	0.9 (230)	1.1 (14)	4.6 (165)					1993–2012	1993–2010	1995–2006	1993–2009	
Belarus					13 (7)				1998–2005				1995–1998
Czech Republic	1.9 (686)	2.2 (747)	1.3 (546)	1.9 (2)					1989–2013	1989–2015	1989–2013	2008–2008	
Estonia	1.2 (108)	1.7 (126)		0.7 (121)	12 (1)	9 (17)	4 (8)	3 (16)	1996–2013	1998–2015	–	1994–2015	1994–2010
Finland	0.6 (1208)	12 (477)	0.3 (925)	4 (187)	18 (20)	13 (35)	6 (13)		1993–2012	1992–1999	1988–2013	1994–1997	1988–1989
Germany	0.9 (68)			1.2 (248)	28 (15)	26 (21)	15 (10)	4 (12)	2004–2009			2004–2015	1988–2010
Italy	0.9 (24)			4.7 (2)	55 (23)	56 (25)	46 (15)	23 (24)	2005–2010			1994–1994	1995–2011
Latvia	1.6 (659)	1.5 (382)	0.4 (161)	3.1 (42)	46 (15)	7 (19)	6 (11)	5 (41)	1994–2009	1994–2009	1996–2009	1994–2008	1994–2003
Lithuania			0.5 (88)	2.7 (128)	17 (8)	13 (17)	13 (7)	4 (18)			2003–2012	1999–2015	1993–2005
Norway	0.4 (576)				83 (2)				1992–2013				1986–1989
Poland	2.2 (58)	3.3 (99)			65 (9)	9 (9)	3 (8)	4 (14)	1993–1996	1993–1996			1988–1991
Portugal	0.7 (33)		0.6 (2)						1994–2001		1999–1999		
Russia	4 (123)	1 (23)			10 (4)	10 (6)	10 (8)	10 (14)	1992–1997	1993–1997			1989–1993
Spain	0.2 (77)	0.2 (78)	0.2 (75)	0.7 (14)		32 (4)	22 (2)	10 (4)	2007–2012	2007–2015	2007–2012	2008–2015	2010–2010
Sweden	1 (277)	0.8 (190)	0.4 (517)	2.7 (152)	84 (8)	18 (4)	9 (8)	3 (5)	1995–2012	1995–2012	1996–2013	1995–2015	1984–1997
Switzerland	66 (4)	47 (5)							1992–1993	1992–1993			
The Netherlands	3.7 (229)	1.7 (75)		2.1 (6)			19 (2)		1984–1999	1993–1999		1993–1998	1993–1997
United Kingdom	9.7 (114)	3.7 (43)							1988–1997	1988–1991			

3.3.3
Mercury

There was a large range between countries in Hg concentrations in PC (3.6–291 ng L^{-1}) (Table 3.3). For Estonia Hg concentrations were the same (100 ng L^{-1}) across water compartments (PC, TF and RW) and showing no variability between sampling occasions (data not shown). The absence of variability in data series and between forest compartments as well as unusually high concentrations in natural water calls for caution if Estonian data is applied for calculations of mass balances or critical loads to forest ecosystem. The high Hg concentrations in PC reported from Russia (291 ng L^{-1}) and Estonia were all sampled before the year 2000. The range in median Hg concentrations in PC sampled after 2000 between countries was 3.6–40 ng L^{-1}. Hg concentrations in TF were reported from Estonia and Sweden (16.5 ng L^{-1}) and RW from Finland (3 ng L^{-1}) and Sweden (3.9 ng L^{-1}). Hg concentrations in LF were reported from Estonia (45 µg kg^{-1}) and Sweden (70 µg kg^{-1}). In soil horizons in Germany and Sweden, Hg was accumulated in organic rich OH-litter layer (63–262 µg kg^{-1}). Deeper soil horizons had lower Hg concentration (30–200 cm: 5–110 µg kg^{-1}) compared to the upper soil horizons (0–10 cm: 5–143 µg kg^{-1}, 10–30 cm: 5–132 µg kg^{-1}). The accumulations of Hg in organic rich soil layers are due to the strong binding capacity of Hg to organic matter and low rates of leaching.

Table 3.3. Mercury concentrations (median (n)) and years with data from subprogrammes within ICP IM sites in member states of the UNECE CLRTAP.

Mercury (Hg)													
	Median (n)								Temporal coverage				
	Subprogramme												
	PC	TF	RW	LF	SC (soil depth cm)				PC	TF	RW	LF	SC
					OH-litter	0–10	10–30	30–200					
	ng L^{-1}			µg kg^{-1}					between years				
Country													
Austria													
Belarus													
Czech Republic													
Estonia	100 (28)	100 (3)	100 (38)	45 (4)	63 (1)	50 (2)	32 (4)	20 (2)	1996–1999	1995–1998	1996–1998	2012–2015	1994–2010
Finland			3 (354)								2003–2013		
Germany	10 (21)				209 (7)	28 (4)			2004–2005				1988–1990
Italy					147 (14)	143 (20)	132 (10	110 (18)					2000–2011
Latvia	40 (69)								2007–2009				
Lithuania						5 (2)	5 (1)	5 (7)					1993–1993
Norway													
Poland													
Portugal													
Russia	291 (55)								1992–1994				
Spain													
Sweden	3.6 (45)	16.5 (76)	3.9 (16)	70 (117)	262 (7)	21 (3)	53 (5)	20 (3)	1996–2012	1997–2012	1997–2011	1999–2014	1984–1997
Switzerland				370 (1)								1996–1996	
The Netherlands													
United Kingdom													

3.3.4
Copper

Copper concentrations in PC did not show large variation between countries (0.5 (Spain)–17.4 (United Kingdom) µg L^{-1}) with the highest concentrations being reported during the period before year 2000 (Table 3.4). Data that covers only a period after 2000 have Cu concentrations in PC between 0.5 µg L^{-1} and 6.0 µg L^{-1} (Italy). Cu concentrations in TF vary between 1.1 µg L^{-1} and 23.5 mg L^{-1}. Cu shows a considerably lower enrichment after forest canopy interception (TF) compared to PC and compared to priority HM: Cd, Pb and Hg. Also concentrations of Cu in RW (0.3–4.0 µg L^{-1}) are comparable with Cu concentrations in PC, indicating accumulation in the catchments. Between soil horizons Cu concentrations are almost comparable in OH-litter horizon (1.5–10.8 mg kg^{-1}) and mineral soil horizons at 0–10 cm (0.4–19.9 mg kg^{-1}), 10–30 cm (0.4–19.2 mg kg^{-1}) and 30–200 cm (1.7–22.7 mg kg^{-1}).

Table 3.4. Copper concentrations (median (n)) and years with data from subprogrammes within ICP IM sites in member states of the UNECE CLRTAP.

Copper (Cu)													
	Median (n)								Temporal coverage				
	Subprogramme												
	PC	TF	RW	LF	SC (soil depth cm)				PC	TF	RW	LF	SC
					OH-litter	0–10	10–30	30–200					
	µg L^{-1}			mg kg^{-1}					between years				
Country													
Austria	4.0 (415)	6.1 (317)	1.9 (92)	5.9 (165)					1993–2012	1993–2010	1998–2012	1993–2009	
Belarus	4.0 (100)		4.0 (117)		2.0 (7)				1998–2005		1995–2014		1995–1998
Czech Republic	1.5 (29)		1.0 (88)						1990–1999		1991–1999		
Estonia	5.6 (165)	8.5 (200)		3.8 (126)	1.5 (1)	4.0 (17)	4.5 (8)	2.3 (20)	1996–2013	1998–2015		1994–2015	1994–2010
Finland	1.0 (1205)	2.5 (501)	0.3 (926)	4.4 (233)	5.7 (20)	7.0 (35)	5.1 (13)		1993–2012	1992–1999	1988–2013	1904–1997	1988–1989
Germany	1.2 (68)			5.7 (384)	10.8 (10)	10.3 (11)	6.1 (8)	8.2 (11)	2004–2009			1904–2015	1990–2010
Italy	6.0 (9)			12.0 (19)	13 (23)	9.0 (25)	7.0 (15)	8.2 (24)	2005–2010			1994–2000	1995–2011
Latvia	1.9 (702)	3.6 (408)	0.9 (172)	3.0 (42)	4.3 (15)	1.2 (19)	1.8 (11)	1.7 (41)	1994–2009	1994–2009	1996–2009	1994–2008	1994–2003
Lithuania			3.2 (120)	2.9 (128)	2.5 (9)	1.5 (19)	1.6 (8)	2.4 (27)			2000–2012	1999–2015	1993–2005
Norway	0.8 (60)				9.7 (2)				2011–2013				1986–1989
Poland	2.0 (57)	2.7 (100)	2.3 (5)		9.0 (9)	0.4 (7)	0.4 (7)	5.1 (14)	1993–1996	1993–1996	1996–1996		1988–1991
Portugal	1.1 (66)		1.9 (16)						1994–2001		1999–2001		
Russia	2.0 (56)	2.1 (23)			10.0 (4)	10.0 (6)	10.0 (6)	10.0 (12)	1992–1997	1993–1997			1989–1993
Spain	0.5 (77)	1.1 (78)	0.6 (80)	4.7 (14)		19.9 (4)	19.2 (2)	22.7 (4)	2007–2012	2007–2015	2007–2012	2008–2015	2010–2010
Sweden	0.8 (245)	1.2 (182)	0.3 (474)	3.5 (147)	10.0 (8)	2.1 (4)	3.1 (6)	5.9 (5)	1997–2012	1995–2012	1999–2013	1996–2015	1987–1997
Switzerland	2.0 (229)	3.4 (75)		2.1 (6)			1.9 (2)		1984–1999	1993–1999		1993–1998	1993–1997
The Netherlands	1.2 (114)								1988–1997				
United Kingdom	17.4 (27)	23.5 (24)							1991–1993	1991–1993			

3.3.5
Zinc

Zn concentrations in PC varied between 2.4 µg L^{-1} (Finland) and 24.0 µg L^{-1} (Czech Republic) and Zn concentrations were slightly higher in TF (5.6–35.5 µg L^{-1}) (Table 3.5). As for Cu, Zn concentrations in RW (2.4–19 µg L^{-1}) were comparable to the Zn concentrations found in PC and TF. Surprisingly, the lowest median Zn concentrations in LF (21.6) occurred in Czech Republic, however, with the highest Cu concentration in PC. The highest median Zn concentration in LF was 113.8 mg kg^{-1} (Italy). Median Zn concentrations in SC were similar in organic rich soil horizon OH-litter layer (19–85 mg kg^{-1}) and mineral soil horizon 0–10 cm (6–102 mg kg^{-1}), 10–30 cm (8–93 mg kg^{-1}) and 30–200 cm (6–106 mg kg^{-1}). Such conditions differed from the other HM patterns.

Table 3.5. Zinc concentrations (median (n)) and years with data from subprogrammes within ICP IM sites in member states of the UNECE CLRTAP.

Zinc (Zn)													
	Median (n)								Temporal coverage				
	Subprogramme												
	PC	TF	RW	LF	SC (soil depth cm)				PC	TF	RW	LF	SC
					OH-litter	0–10	10–30	30–200					
	µg L^{-1}			mg kg^{-1}					between years				
Country													
Austria	11.7 (527)	16.9 (326)	11.5 (146)	58.3 (166)					1993–2012	1993–2010	1994–2012	1993–2009	
Belarus	21.0 (105)		11.0 (134)		19 (7)				1998–2005		1996–2014		1995–1998
Czech Republic	24.0 (890)	34.0 (737)	19.0 (432)	21.6 (2)					1989–2013	1989–2015	1989–2013	2008–2008	
Estonia	13.0 (141)	23.5 (185)		48.2 (126)	23 (1)	28 (17)	13 (10)	13 (22)	1996–2013	1998–2015		1994–2015	1994–2010
Finland	2.4 (1206)	13.9 (592)	2.4 (927)	56.8 (234)	30 (20)	13 (35)	10 (13)		1993–2012	1992–2002	1988–2013	1994–1997	1988–1989
Germany	6.6 (68)			32.1 (382)	55 (10)	53 (14)	36 (8)	42 (12)	2004–2009			2004–2015	1990–2010
Italy	13.0 (24)			113.8 (19)	85 (23)	58 (25)	66 (15)	65 (24)	2005–2010			1994–2000	1995–2011
Latvia	18.7 (664)	28.2 (402)	8.0 (158)	50.7 (42)	38 (15)	7 (19)	12 (11)	7 (41)	1994–2009	1994–2009	1996–2009	1994–2008	1994–2003
Lithuania			12.0 (120)	45.0 (127)	21 (9)	7 (19)	8 (8)	6 (27)			2000–2012	1999–2015	1993–2005
Norway	2.5 (567)								1992–2013				
Poland	16.1 (58)	35.5 (103)	13.0 (4)		55 (9)	6 (9)	10 (8)	8 (18)	1993–1996	1993–1996	1996–1996		1988–1991
Portugal	16.3 (68)		10.0 (20)						1994–2001		1999–2001		
Russia	9.5 (60)	17.0 (23)			40 (4)	20 (6)	26 (8)	30 (12)	1992–1997	1993–1997			1989–1993
Spain	4.9 (62)	5.6 (70)	4.8 (49)	34.1 (14)		102 (4)	93 (2)	106 (4)	2007–2012	2007–2015	2007–2012	2008–2015	2010–2010
Sweden	5.4 (274)	12.1 (190)	3.6 (474)	81.9 (147)	60 (8)	7 (4)	16 (7)	18 (5)	1995–2012	1995–2012	1999–2013	1996–2015	1984–1997
Switzerland	9.2 (170)	9.0 (75)		36.9 (6)			9 (2)		1988–1999	1993–1999		1993–1998	1993–1997
The Netherlands	6.6 (114)								1988–1997				
United Kingdom	67.5 (6)	19.1 (24)							1991–1992	1991–1993			

3.4
Conclusions

Data for HM concentrations in forest compartments is needed for future estimates of the load and exposure from HM on sensitive receptors. Values presented herein, with some exceptions with extreme values originating from mainly old and small number of sampling occasions (i.e. Cd and Hg in Russia, and Cu from the United Kingdom), represent background concentrations for HM in compartments (PC, TF, RW and LF) and pools (SC) across UNECE member states. In future evaluations of HM data from ICP IM sites, it will also be important to understand processes that cause variations, in which way HM are transported and accumulated in forest compartments with expose to sensitive receptors in terrestrial and aquatic environments.

The data presented did not cover all forest compartments or countries in the ICP IM network. Data for Cd covering all forest compartments (PC, TF, LF, RW and SC) was presented from Finland, Latvia, Spain, and Sweden even though all soil layers were not covered for all the countries mentioned. Austria had Cd data from all forest compartments except data for SC. Poland has also Cd data from all forest compartments, except LF. Estonia and the Netherlands have Cd data that covers all forest compartments except RW. Latvia, Spain and Sweden were the only countries that have Pb concentration data from all forest compartments and soil depths. Czech Republic had Pb data for PC, TF, RW, and LF but data for SC were not covered. Estonia had data from PC, TF, LF, and SC but not RW. Data of Hg concentrations from different forest compartments were present from a number of countries (Estonia (PC, TF, RW, LF, SC), Finland (RW), Germany (PC, SC), Italy (SC), Latvia (PC), Lithuania (SC), Russia (PC), Sweden (PC, TF, RW, LF, SC), and Switzerland (LF)). Two countries, Estonia and Sweden, had data for Hg concentrations from all forest compartments. Countries with Cu and Zn concentration data from all forest compartments were Finland, Latvia, Spain, and Sweden. Estonia also has data from Cu and Zn concentrations from almost all forest compartments except RW, while Poland also had data from all compartments except LF.

Accumulation patterns in SC show that especially Cd, Pb, and Hg accumulated in the ecosystems and have higher concentration in OH-litter layer compared to deeper mineral soil. The strong affinity of HM for organic matter is the main reason for this pattern. The strong binding and slow leakage cause slow response to changes in atmospheric deposition patterns. In case conditions change (e.g. changing climate) stores of HM can be released from stores in soils and be transported to aquatic environments where HM become a potential threat to sensitive ecosystems downstream. For Hg it is actually shown that despite decreasing Hg deposition, Hg concentrations in OH-litter layer do not respond and actually increase at some sites in Sweden (Åkerblom et al. 2015). Concentration values from the deepest soil horizons (30–200 cm) (Cd: 0.02–1.29 mg kg^{-1}; Pb: 3–23 mg kg^{-1}; Hg: 5–110 µg kg^{-1}; Cu: 1.7–22.7 mg kg^{-1}; Zn: 6–106 mg kg^{-1}) can be considered to represent parent material that are relatively unaffected by atmospherically deposited HM. The background HM concentrations in mineral soil layers are also influenced by the geogenic background within each region.

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Annex 1

Lago Nero – an example of mountain lake monitoring in a changing Alpine cryosphere

Report on National ICP IM activities in Switzerland

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Background

Deposition of atmospheric pollutants is a key environmental issue for many ecosystems, especially on the southern slopes of the Italian and Swiss Alps which receive substantial inputs from the Po valley in adjacent Italy[1]. Concerning major atmospheric pollutants with acidifying or eutrophying effects, inputs in this region peaked between 1965 and 1980 for sulphur dioxide and around 1985 for nitrogen oxides and probably ammonia[2]. High-alpine catchments are particularly sensitive to atmospheric pollutants but also to other current environmental issues including climate change, mainly as a consequence of their low chemical and physical buffer capacity and their sensitive biological communities. The various and complex effects of atmospheric pollutants and of environmental change in general warrants an integrative monitoring of these ecosystems. The catchment of Lago Nero at the head of Val Bavona in Ticino (Switzerland) was chosen as an ICP IM site due to the postulated sensitivity of its ecosystems to atmospheric pollutants and climate change but also due to its remote location which minimizes direct anthropogenic impacts[3].

The catchment of Lago Nero contains an intact rock glacier on the higher slopes. During build-up, rock glaciers can incorporate and store substantial quantities of deposited atmospheric pollutants. During ice melt, intact rock glaciers then release dissolved chemicals derived from pollutants, often resulting in characteristic chemical signatures[4]. As a consequence, their meltwater can substantially alter chemical composition of receiving surface water bodies, which may affect biological communities[4]. Our study aimed at quantifying ground ice distribution and characteristics in the Lago Nero catchment and its potential to alter the chemical composition of small streams in the catchment.

The study site

The Lago Nero catchment is southwest-facing, with elevations ranging from 2385 m to 2842 m asl. The catchment has an area of 74 ha (lake surface: 13 ha), mainly composed of gneissic bedrock with patches of grassy vegetation and shallow soils. The snow cover period extends approximately from November to June and for a similar period the lake is ice-covered. The mean slope of the catchment is extremely high (84%). The intact rock glacier is located in the south-eastern part of the catchment, with a front

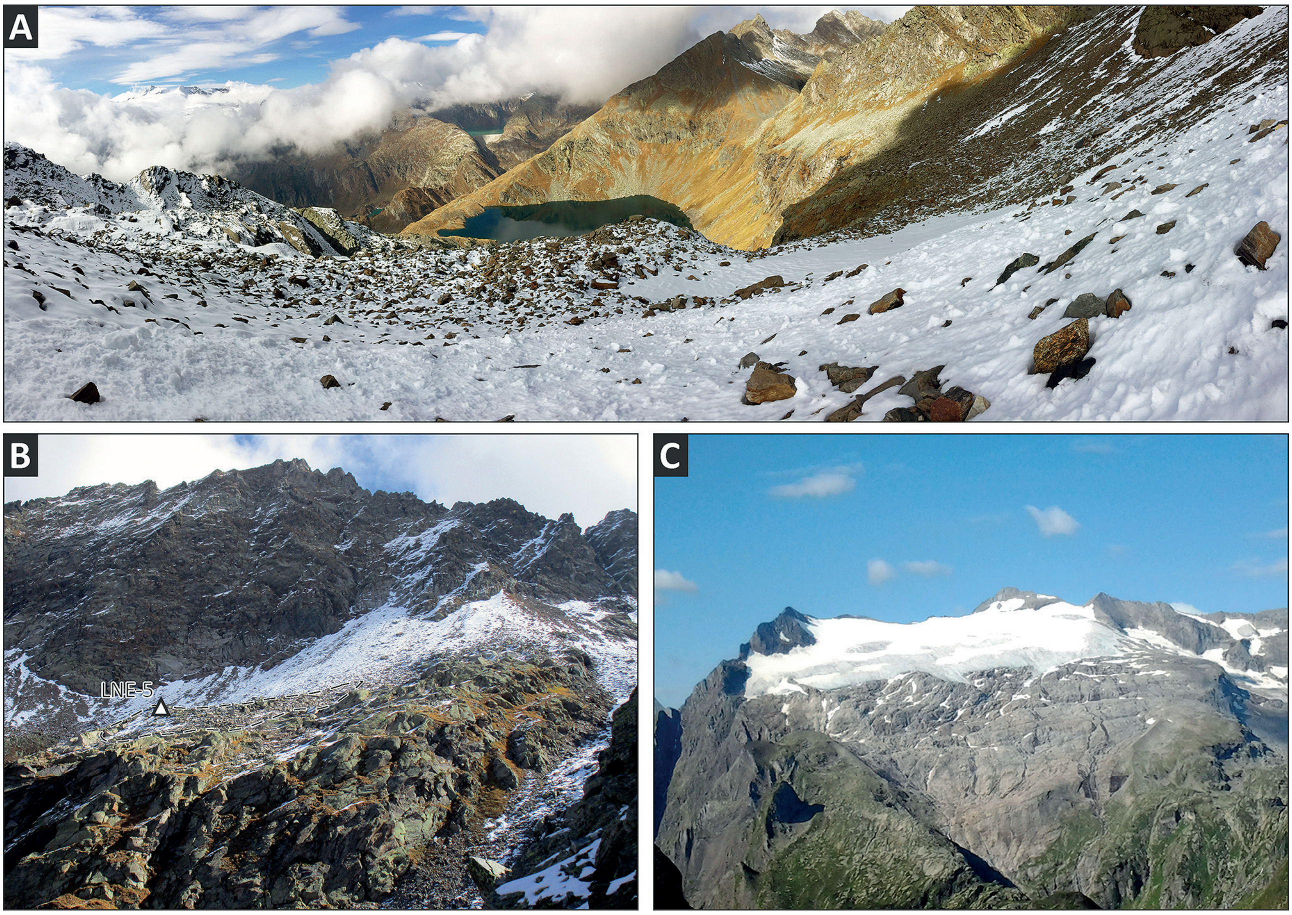

Figure 1. A. View of Lago Nero from the rooting zone of the intact rock glacier in the south-eastern part of the catchment (photo S. Rioggi, 12.10.2015). B. The upper part of the Lago Nero catchment with the intact rock glacier (the front boundaries are dashed), and location of the temperature datalogger LNE-5 (photo C. Scapozza, 12.10.2015). C. View of the Basòdino glacier from the Lago Nero rock glacier (photo C. Scapozza, 17.08.2016).

altitude of 2560 m asl (Fig. 1A, B). Mean Annual Air Temperature (MAAT) and Mean Annual Ground Surface Temperature (MAGST) for the hydrological year 2015/2016 (October 2015 to September 2016), measured close to the lake outflow (temperature loggers LNE-1 and LNE-2 at 2400 m asl; Fig. 2), was 1.5°C and 1.2°C, respectively. Mean Annual Precipitation (MAP) measured at the nearby MeteoSwiss station in Robièi (1896 m asl), is 2420 mm (1981–2010 mean).

Geomorphological mapping and cryosphere monitoring

Cryosphere monitoring at Lago Nero site began in autumn 2015, to characterize the catchment geomorphology, assess the permafrost distribution, and monitor the rock glacier and its contribution to the water chemistry of Lago Nero. Catchment geomorphology was assessed by digital mapping on swissimage orthophoto (©swisstopo) and on swissALTI3D 2m hillshaded Digital Elevation Model (©swisstopo), focusing on landforms, ground texture and the presence of vegetation[5] (Fig. 2). The potential distribution of discontinuous permafrost was mapped using a regional empirical topoclimatic model, based on the variables of aspect and altitude, derived from the rock glacier inventory of the Ticino Alps[6]. Ground Surface Temperature (GST) monitoring started in October 2015 at three locations on the rock glacier (Figs. 1B, 2). Temperatures are measured every two hours with UTL-3 Scientific Dataloggers (Geotest AG, with an accuracy of ± 0.1°C). Water temperature and chemistry of a spring located close to the rock glacier (Fig. 2) are also monitored.

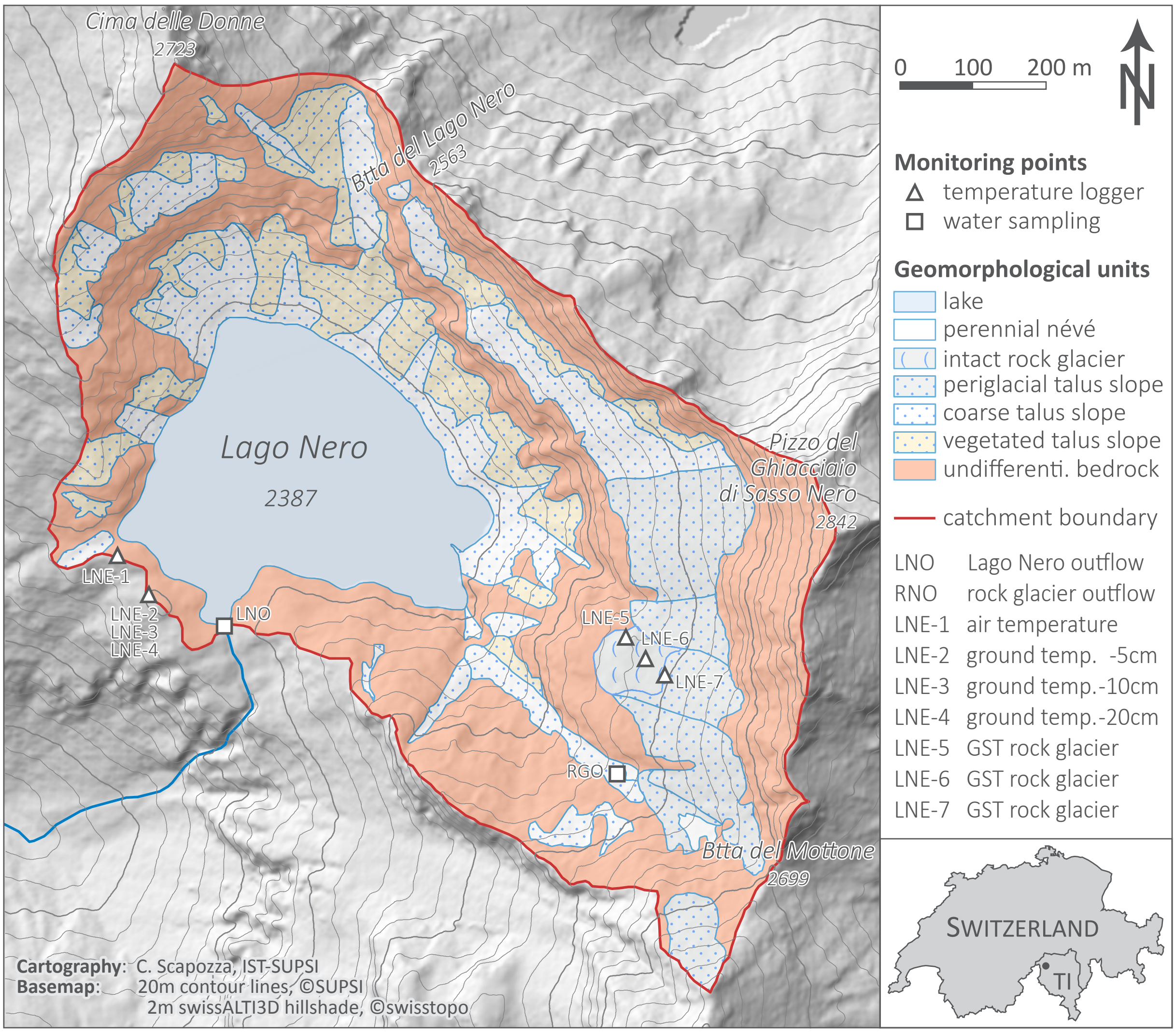

Figure 2. Geomorphological map of the Lago Nero catchment and location of the monitoring points discussed in this paper.

Assessment of local permafrost distribution and monitoring

Local permafrost distribution was assessed using the geomorphological map and the potential distribution of discontinuous permafrost. Geomorphological mapping allowed the identification of two perennial névés and the definition of coarse debris units favourable to potential ground ice storage (permafrost-ice in rock glaciers and talus slopes and debris-covered ice patches), such as intact rock glaciers, periglacial talus slopes and coarse talus slopes (Fig. 2). Considering that permafrost in bedrock usually occurs several hundred meters above permafrost in debris, its presence is improbable in the Lago Nero catchment[7]. The estimation of local permafrost distribution was thus improved by focussing exclusively on the coarse debris units and the presence of perennial névés (Fig. 3). Based on this assessment permafrost is potentially present across 18.75% of the catchment surface (lake surface excluded), corresponding to 0.11 km^2. Considering the high porosity of coarse debris, permafrost zones can store relatively significant amounts of ground ice (20-40% of the total volume) even outside the rock glacier surface[8]. Assuming a warming rate of 0.84°C/100a since 1850[ref 9] and a local lapse rate of 0.6°C/100m, it is possible to consider a belt of permafrost degradation since the end of the Little Ice Age (the last cold period with

Alpine permafrost in climatic equilibrium, ended in 1850) in the Southern Swiss Alps of ca. 230 m in altitude[9, 10]. As a consequence, the zone of potential ground ice melting covers 16.05% of the Lago Nero catchment, representing 85.6% of the total surface with potential permafrost conditions (Fig. 3).

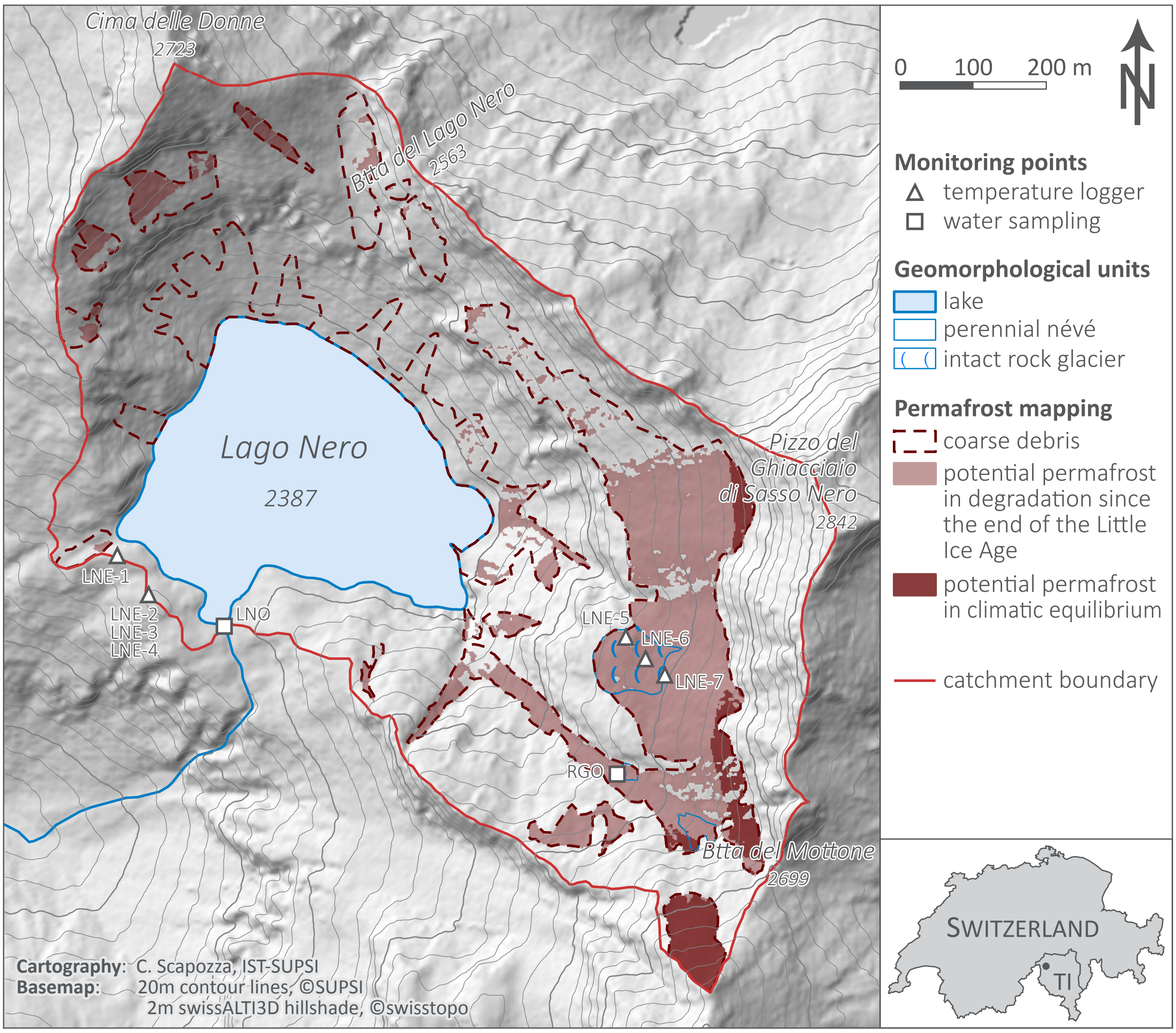

Figure 3. Permafrost distribution in the Lago Nero catchment.

The first results of the thermal monitoring strategy adopted for assessing permafrost degradation and the subsequent ground ice melting indicates a variable temperature regime on the intact rock glacier (Fig. 4). GST for LNE-5 datalogger, located at the top of the rock glacier front (Fig. 1B), presents a very high variability due to snow depletion by wind facilitated by the convex shape of the slope. At this location the freezing potential is very high, with a January-February-March (JFM) mean GST of -6.3°C. The loggers LNE-6 and LNE-7, placed on the body and on the rooting zone of the rock glacier, respectively (Fig. 2), showed a winter equilibrium temperature (WEqT) lower than -2.5°C and a JFM mean GST of -2.3°C and -3.1°C, confirming the probable permafrost presence within this landform[11].

The comparison between water chemistry measured at the rock glacier outflow (RGO) and at the Lago Nero outflow (LNO) shows high amounts of ammonia and sulphate in the periglacial zone with respect to the lake surface water (Tab. 1). Ammonia measured at the RGO exceeded the values measured at the LNO by a factor

> 5.0, sulphate by a factor between 2.1 and 5.7, and nitrate by a factor between 2.0 and 4.0. Measurements performed later during the unfrozen period showed a higher difference between the RGO and the LNO. This is also the case for electrical conductivity, which increased significantly at the RGO from August to October (although these measurements were not carried out during the same year).

With respect to deposition of atmospheric pollutants measured in vicinity to Lago Nero (LND; Table 1), conductivity at the RGO was higher, whereas there were no significant differences concerning nitrate. The main difference was related to sulphate concentrations, which were from 8 to 40 times higher at the RGO. RGO presented higher concentrations of sulphate even in relation to the Maggia and Verzasca rivers, the two main rivers of the Western Ticino Alps, which present mean concentrations of 9.6 and 0.6 mg SO_4 L^{-1} for 2016 respectively[12].

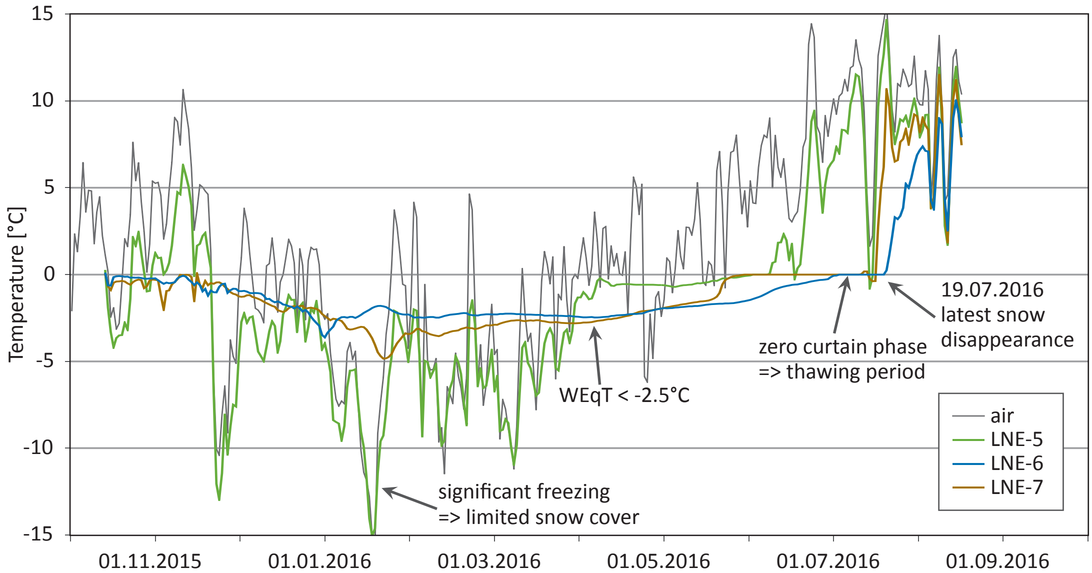

Figure 4. Ground surface temperatures recorded on the Lago Nero rock glacier for the hydrological year 2015/2016. More details in the text.

Table 1. Comparison of water temperature, conductivity and chemistry measured at the rock glacier outflow (RGO) and at the Lago Nero outflow (LNO), and mean atmospheric deposition measured at the Lago Nero (LND).

Parameter		Temp.	Conduct. 20°C	Ammonia [NH_4]	Nitrate [NO_3]	Sulphate [SO_4]
Unit		[°C]	[mS/cm]	[mg N/L]	[mg N/L]	[mg SO_4/L]
12.10.2015	RGO	-	79.0	< l.o.q.	0.4	31.0
	LNO	7.6	14.0	3.1	0.1	2.2
	RGO/LNO	-	5.6	-	4.0	14.1
17.08.2016	RGO	0.4	16.0	38.8	0.2	5.7
	LNO	10.9	15.0	2.3	0.1	2.7
	RGO/LNO	-	1.1	16.9	2.0	2.1
20.09.2016	RGO	0.4	30.0	40.3	0.3	10.7
	LNO	10.0	17.0	7.8	0.1	2.7
	RGO/LNO	-	1.8	5.2	3.0	4.0
2015-2016	LND	-	8.9	225.7	0.3	0.7

Does the cryosphere restitute atmospheric pollutants of the 1960ies to the 1990ies?

Temperature measurements carried out on the Lago Nero intact rock glacier confirmed the permafrost presence within this landform. Considering the ground surface characteristics, aspect and elevation, coarse debris surfaces of the south-eastern part of the catchment are probably perennially frozen and can store significant amounts of ground ice. Permafrost warming since the end of the Little Ice Age probably induced ground ice melting during the last decades, affecting more than 80% of the potential permafrost area of the Lago Nero catchment.

Ground ice melting can substantially alter the physical and chemical characteristics of surface water close to the RGO. Typical high conductivity of cold water emerging close to the rock glacier indicates an accelerated ground-ice melting. Due to the fact that ground ice is in contact with rock debris for long periods (decades, centuries or even millennia), the ionic enrichment explains the higher conductivity of resulting meltwater compared to low-conductivity snowmelt or meteoric waters[13]. Conductivity measurements carried out in the Lago Nero catchment are consistent with this pattern: measurements carried out later in autumn (with less snow melt contributing to flow), showed higher influence of ground ice melting in the water characteristics.

How can we explain the amounts of ammonia, nitrate and sulphate measured at RGO? Mass balance and front variation measurements carried out at the Basòdino glacier, located 5 km southwest of Lago Nero (Fig. 1C), indicate ice accumulation between 1964 and 1994, followed by an almost uninterrupted period of ice ablation (15 of the 20 years between 1994 and 2014 had a negative mass balance)[14]. It is probable that during the period 1964–1994, ice accumulated also in the higher parts of the Lago Nero catchment, as indicated by the number of perennial névés observed on aerial photographs of late summer/beginning of autumn from that period. The presence of perennial névés increases the ground ice mass by their meltwater refreezing or by their debris burial[15]. As a consequence, it is probable that ammonia, nitrate and sulphate was stored in the cryosphere during the 1960ies to 1990ies following deposition of atmospheric pollutants. Their high amounts measured today close to the Lago Nero rock glacier are consistent with the significant melting of ground ice in the last decades caused by warming of Alpine permafrost terrains in Southern Switzerland[16].

Conclusions

Assessment of local permafrost distribution and monitoring, as well as the analysis of physical and chemical characteristics of water in the periglacial belt of the catchment shows that Lago Nero is particularly sensitive to changes in the cryosphere, in particular concerning an increased permafrost degradation and related ground ice melting. The probable storage of ground ice during the 1964–1994 period (deduced from the mass balance of the nearby Basòdino glacier and by the presence of perennial névés) and its significant melting in the last decades, may explain the high conductivity and amounts of ammonia, nitrate and sulphate measured in the outflow of the rock glacier. As a consequence, in high-altitude hydrosystems such as that of Lago Nero, the melting of inherited ground ice may release atmospheric pollutants stored in the cryosphere several decades before. This finding exemplifies the sensitivity of the Lago Nero catchment to climate change.

Acknowledgements

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Annex 2

Simultaneous analysis of coniferous forest state parameters and atmospheric deposition data series by ICP IM and EMEP in Central Forest Nature Reserve

Report on National ICP IM activities in Russia

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The problem of air pollution and its effects on the natural environment or particular ecosystems is one of the greatest global challenges faced by humanity. In this regard, the assessment of connections between the bioindication parameters and air pollutants is an important topic to be developed, especially for background areas.

The Russian Federation participates in a number of international environmental monitoring programmes established and working under the Convention on Long-range Transboundary Air Pollution (CLRTAP). Some of the programmes include long-term measurements and observations on the background areas. The data series and monitoring results of European Monitoring and Evaluation Programme (EMEP) and International Cooperative Programme on Integrated Monitoring of Air Pollution Effects on Ecosystems (ICP IM) were used in this research together. Statistical analysis of the data was carried out with help of OpenOffice Calc software.

The main purpose of this study was to identify a relationship between the measured values of the parameters (features) of coniferous forest stands, and levels of pollutants in atmospheric precipitation (the concentrations and their wet deposition). Additional objectives of this study were the evaluations of:

- the changes of forest stands by using defoliation (DF) and discoloration (DC) parameters;
- the effects on the condition of the forest stands of fluxes of sulphate, nitrate, chloride and ammonium compounds, as well as sodium, magnesium, calcium and potassium.

The study on the condition of forest stands was carried out according to the recommended observation methods of Forest damage subprogramme in ICP IM Manual. Observations were made on permanent sample plots at the Central Forest Biosphere reserve (CFBR), IM site RU13, from year 2009 to 2016. The assessment of the condition of the pine and spruce forest stands was done by estimating the defoliation and discoloration (Fig.1).

Data on the content of pollutants in precipitations were obtained from the observations of the EMEP station located on the territory of CFBR. The concentrations of sulphate, nitrate, chloride, ammonium, and cations (sodium, magnesium, calcium, and potassium) from daily samples were used. The precipitation amounts obtained from meteorological data at the station in CFBR were used for calculating deposition fluxes.

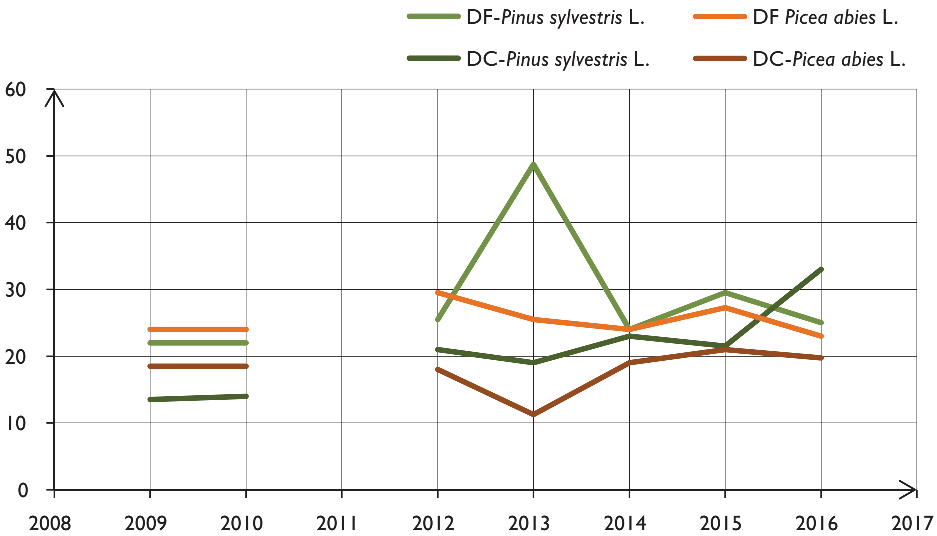

Figure 1. Interannual fluctuations of defoliation (DF) (%) and discoloration (DC) (%) in stands of Scots pine (*Pínus sylvestris*) and spruce (*Pícea abies*).

The observations demonstrated that there were no evident trends of defoliation and discolorations in pine or spruce stands. No significant correlations were determined for interannual fluctuations (see Fig.1). This fact requires further research as it is not consistent with our previous results.

The vital structures were calculated for both stands[1,2]. The Figures 2 and 3 demonstrate that there are no trends for changes of forest stand condition. Some deterioration of the condition was found for the Scots pine stand (Fig.3), but not for the spruce stand.

To assess the possible relationships between vegetation and atmospheric pollution a statistical study was carried out with the data series mentioned above and total wet deposition or concentrations of pollutants (in terms of the main elements). Correlation of the current year forest parameters (discoloration, defoliation) was carried out with concentrations of precipitation, contaminants of the current year and, separately,

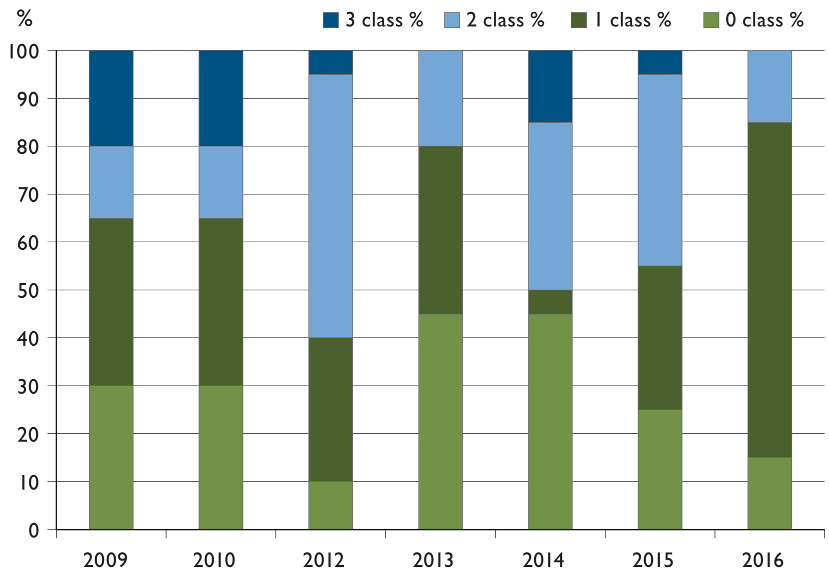

Figure 2. Vital structure of spruce, *Picea abies* L.

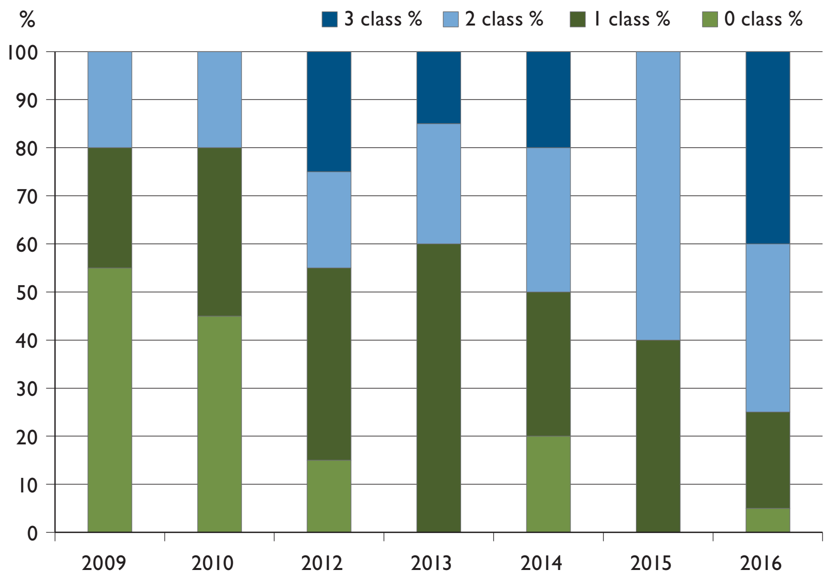

Figure 3. Vital structure of Scots pine, *Pinus sylvestris* L.

with ones of the previous year. This choice to compare time-series with and without a shift of 1 year was associated with the fact that several growth parameters of the current year depend on the environmental conditions of previous year (Rumyantsev & Melnik 2009)[3]. The results of correlation analysis for the obtained significance level (p) no less than 0.05 are presented in Tables 1 and 2.

Negative significant correlation between the current year H^+ wet deposition (calculated from pH) and *Picea abies* discoloration was found. At the same time, also a correlation between the previous year H^+ wet deposition and defoliation was found. For the research area generally pine is more susceptible to contaminants. DC of *Pinus sylvestris* is the most sensitive parameter.

Table 1. Coefficients of correlations between the parameters of coniferous stands and total wet deposition of pollutants for current(C) and previous (P) year. (p = 0.05)

Stand	Parameter	SO_4(S)	NO_3(N)	NH_4(N)	Na	Mg	Ca	Cl	K
Pinus sylvestris L.	DF			-0.63C 0.63P					-0.63C
Picea abies L.	DF						0.58C		
Pinus sylvestris L.	DC	-0.94C -0.73P			-0.68C -0.60P	-0.73C		-0.64C -0.66P	-0.73C -0.63P
Picea abies L.	DC			-0.59P					

Table 2. Coefficients of correlations between the parameters of coniferous stands and concentration of pollutants in precipitation for current(C) and previous (P) year. (p = 0.05)

Stand	Parameter	SO_4(S)	NO_3 (N)	NH_4(N)	Na	Mg	Ca	Cl	K
Pinus sylvestris L.	DF	-0.69P	0.67C						-0.61C
Picea abies L.	DF	-0.65C							
Pinus sylvestris L.	DC		0.55P	0.73P			0.59C	-0.58P	
Picea abies L.	DC	0.58P		0.74C					

Despite the fact that the general deterioration was illustrated in the vital structure for more sensitive forest stand (*Pinus sylvestris* L.) (Fig. 3), we found that defoliation (DF) and discoloration (DC) of both forest stands did not demonstrate a significant trend at the territory of CFBR for the period under investigation. Analyses of vital structure also showed that there is no correlation between changes of spruce and pine conditions. However, significant correlations between the coniferous conditions and pollution levels in precipitations were detected.

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Annex 3

Report on National ICP IM activities in Sweden in 2015

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Introduction

The Swedish integrated monitoring programme is run on four sites distributed from south central Sweden (SE14 Aneboda), over the middle part (SE15 Kindla), to a northerly site (SE16 Gammtratten). The long-term monitoring site SE04 Gårdsjön F1 is complementary on the inland of the West Coast and has been influenced by long-term high deposition loads. The sites are well-defined catchments with mainly coniferous forest stands dominated by bilberry spruce forests on glacial till deposited above the highest coastline. Hence, there has been no water sorting of the soil material. Both climate and deposition gradients coincide with the distribution of the sites from south to north (Table 1). The forest stands are mainly over 100 years old and at least three of them have several hundred years of natural continuity. Until the 1950's, the woodlands were lightly grazed in restricted areas. In early 2005, a heavy storm struck the IM site Aneboda, SE14. Compared with other forests in the region, however, this site managed rather well and roughly 20–30% of the trees in the area were storm-felled. In 1996, the total number of large woody debris in the form of logs was 317 in the surveyed plots, which decreased to 257 in 2001. In 2006, after the storm, the number of logs increased to 433, corresponding to 2711 logs in the whole catchment. In later years, 2007–2010, bark beetle (*Ips typographus)* infestation has almost totally erased the old spruce trees. In 2011 more than 80% of the trees with a breast height over 35 cm where dead (Löfgren et al. 2014) and currently almost all spruce trees with diameter of ≥20 cm are gone.

Table 1. Geographic location and long-term climate and hydrology at the Swedish IM sites.

	SE04	**SE14**	**SE15**	**SE16**
Latitude; Longitude	N 58° 03′; E 12° 01′	N 57° 05′; E 14° 32′	N 59° 45′; E 14° 54′	N 63° 51′; E 18° 06′
Altitude, m	114–140	210–240	312–415	410–545
Area, ha	3.7	18.9	20.4	45
Mean annual temperature, °C	+6.7	+5.8	+4.2	+1.2
Mean annual precipitation, mm	1000	750	900	750
Mean annual evapotransporation, mm	480	470	450	370
Mean annual runoff, mm	520	280	450	380

In the following, climate, hydrology, water chemistry and some ongoing work at the four Swedish IM sites are presented (Löfgren 2016).

Climate and Hydrology in 2015

In 2015, the annual mean temperatures were higher (0.8–2.1 °C) compared to the long-term mean (1961–1990) for all four sites. Largest deviation occurred at the northern SE16 site. Compared with the measured time series, 15 years at site SE16 and 19 years at the other sites, the temperatures in 2015 were somewhat higher at all the IM sites. The values were slightly lower than in 2014 when temperatures were the highest observed for the whole measurement period with exception for SE15 where temperature was slightly higher in years 1999 and 2000. Low temperatures were observed in 2010 and 2012. The variations between years have been considerable, especially for the last five years, over 3°C. Smaller variations were found at the central site SE15 Kindla, only 1°C.

Precipitation amounts in 2015 compared to the long-term average values (1961–1990) were for SE14 Aneboda 35 mm lower and for SE16 Gammtratten in the north 57 mm lower. For site SE04 Gårdsjön precipitation amount was very high exceeding the long-term mean with 414 mm and also SE15 Kindla showed higher value with 122 mm. In 2012, the precipitation amounts were 3–44% higher than the long-term average for the four sites, while in 2013 all sites had lower values. In 2014, similar or lower precipitation occurred compared to normal for three sites, but for SE04 Gårdsjön high precipitation amount was observed with an exceedance of 332 mm, almost as for 2015.

The characteristic annual hydrological patterns of the catchments are for the southern sites high groundwater levels during winter and lower levels in summer and early autumn. However, at site SE15 Kindla three peaks during May to September were noticed with groundwater levels 0.2 m below ground surface, i.e. on similar level as in spring and autumn. Three periods of high groundwater levels were also noticed in 2014. For SE16 Gammtratten, in the north, snowmelt occurred in April-May with highest water levels in June. The groundwater level has decisive influence on the discharge values (Fig. 1).

In addition to precipitation, evapotranspiration affects the runoff pattern. In 2015, these patterns were fairly typical for the two sites Aneboda and Gammtratten, but low precipitation in the period July to October at Aneboda resulted in low discharges in autumn. High precipitation in January, November and December at SE04 Gårdsjön provided high monthly discharges in winter period. At site SE15 Kindla an early spring snowmelt peak was observed in March and precipitation events in May, July and September provide a flashy discharge pattern with peaks for these three months. For SE14 Aneboda in the south and SE16 Gammtratten in the north the patterns mainly followed the long-term mean and for Kindla the pattern was similar to the previous year (Fig. 1).

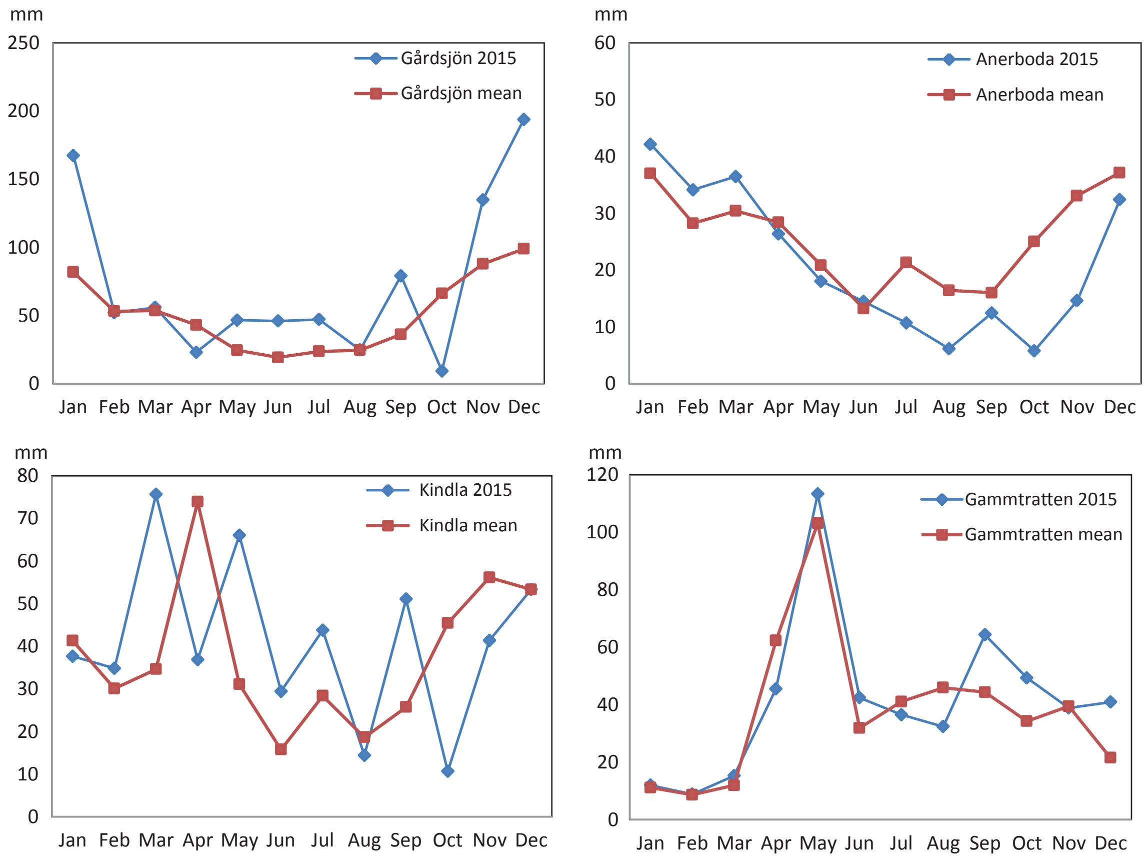

Figure 1. Discharge patterns at the Swedish IM sites in 2015 compared to monthly averages for the period 1996–2015 (mean). Note the different Y-axis scales.

At the two northern sites, generally snow accumulates during winter and the groundwater levels stay low furnishing low discharge. However, warm winter periods with temperatures above 0 °C have during a number of years contributed to snowmelt and runoff also during this season. As a consequence, the spring discharges have been comparably low during snowmelt, deviating from the conditions three decades ago. Such conditions were not obvious in 2015 even though SE16 Gammtratten had fairly high discharge in December.

In 2015 high precipitation and runoff were observed at SE04 Gårdsjön even though interception and total evapotranspiration were high, resembling 2014. At SE15 Kindla annual runoff 495 mm was reasonably high (Table 2), but precipitation 1028 mm and throughfall (586 mm) values were fairly normal. Based on the IM measurements, evapotranspiration was 533 mm, also close to normal.

In 2015, the annual runoff made up 39–72% of the annual precipitation, which is comparable to the 40–60% during previous years. The highest share was found at the northern site SE16 Gammtratten (72%), where partly due to a rather intense snowmelt period and cold climate during the rest of the year, yielding low evapotranspiration (28%), consequently provided high runoff (Table 2). At site Aneboda (SE14), storm felling, followed by bark beetle attacks, have reduced the forest canopy cover, inducing low interception. Actually, the measured throughfall was higher than bulk precipitation by 10% indicating uncertainties. The total evapotranspiration was estimated to 393 mm, a value higher than in the earlier year and closer to the long-term average 470 mm. This mirrors effects of low interception and transpiration of the reduced forest stand.

Table 2. Compilation of the 2015 water balances for the four Swedish IM sites. Measured precipitation and throughfall values at SE15 Kindla site could be biased due to difficulties in snow collection.P – Precipitation, TF – Throughfall, I – Interception, R – Water runoff

	Gårdsjön SE04		Aneboda SE14		Kindla SE15		Gammtratten SE16	
	mm	% of P	mm	% of P	mm	% of P	mm	% of P
Bulk precipitation, P	1306	100	646	100	1028	100	694	100
Throughfall, TF	931	71	710	110	586	57	542	78
Interception, P-TF	375	29	-63	<0	442	43	152	22
Runoff, R	880	67	254	39	495	48	499	72
P-R	426	33	393	61	533	52	194	28

Water chemistry in 2015

Low ion concentrations in bulk deposition (electrolytical conductivity = 1–2 mS m^{-1}) characterise all four Swedish IM sites. The concentrations of ions in throughfall, including dry deposition, were higher at three sites. At SE16 Gammtratten, the conductivity in throughfall (0.8 mS m^{-1}) was the same as in bulk deposition indicating very low sea salt deposition and uptake of ions by the trees. At the two most southern sites, sea salt deposition provides higher ion concentrations, especially at the west coast SE04 Gårdsjön site (7.2 mS m^{-1} in throughfall). The soil water pathways in the catchments soils are fairly short and shallow, providing rapid surface water formation from infiltration to surface water runoff. The acidity in deposition has during the last 10 years been rather similar at all sites with somewhat higher pH values (0–0.5 units) in throughfall compared with bulk deposition. However, in 2015 SE04 Gårdsjön had a throughfall pH on 5.1 while the other three sites had values 5.2–5.4 (Table 3).

Table 3. Mean deposition chemistry values 2015 at the four Swedish IM sites. S and N in kg ha^{-1} yr^{-1}.

	SE04	SE14	SE15	SE16
pH, bulk deposition	5.1	4.9	5.1	5.1
pH, throughfall	5.1	5.4	5.2	5.3
SO_4-S, bulk deposition	5.1	1.9	1.4	1.0
Ntot, bulk deposition	11.1	4.7	3.7	2.3

During the water passage through the catchment soils, organic acids were added and leached to the stream runoff. In the upslope recharge areas, pH in the upper soil layers (E-horizon) was mainly lower than in throughfall. However, in the peat in discharge areas at SE15 Kindla and SE16 Gammtratten, pH was higher compared to throughfall while it was the opposite at SE04 Gårdsjön and SE14 Aneboda with pH 4.5 and 5.0, respectively. Buffering capacities in recharge area soil water and groundwater varied between negative and positive values, but were frequently on the negative side. In the discharge areas, the buffering capacity in groundwater was fairly high with ANC over 0.04 mEq L^{-1} and with bicarbonate (HCO_3^-) present at Kindla and Gammtratten at average concentrations of 0.20 and 0.02 mEq L^{-1}, respectively. The stream waters were acidic with pH values below 4.8 at all sites except Gammtratten having a pH of 5.6. The stream water buffer capacity was positive at all sites, even though at Kindla ANC was close to 0 mEq L^{-1}. Anions of weak organic acids contributed to the positive ANC and bicarbonate contributed at SE16 Gammtratten.

The share of major anions in deposition was similar for sulphate, chloride and nitrate for three of the sites, while chloride dominated at SE04 Gårdsjön due to the proximity of the sea. In throughfall, organic anions contributed significantly at all four sites. The chemical composition changed during the passage of catchment soils and sulphate concentrations were higher in stream water compared with deposition, indicating desorption or mineralization of previously accumulated sulphur in the soils. In Aneboda, nitrification contributed to fairly high nitrate values (0.15–0.18 mEq L^{-1}), which added acidity, yielding comparably low pH and ANC.

Besides effects on ANC and pH, the stream water chemistry is to a considerable extent influenced by organic matter. At Aneboda (SE14), the DOC concentration was high with 31 mg L^{-1} while the other sites Gårdsjön (SE04), Kindla (SE15) and Gammtratten (SE16) showed lower values 14, 10, and 10 mg L^{-1}, respectively. Organic anions and HCO_3 made up about half of the anion flow at Gammtratten, while these constituents only reached about 20% at the other three sites. High DOC concentrations create prerequisites for metal complexion and transport, as well as high organic nitrogen fluxes. The organic nitrogen concentrations in stream water ranged from 0.21 to 0.81 mg N L^{-1}. The shares of Norg/Ntot were 82–97%, somewhat higher shares compared to the previous year, and with SE14 Aneboda having the lowest share and SE16 Gammtratten the highest. At SE14 Aneboda, the average concentration of inorganic nitrogen in stream water was 0.18 mg N L^{-1}, which was high compared with 0.006–0.044 mg N L^{-1} at the other sites. The high inorganic nitrogen concentrations at Aneboda are related to the forest dieback.

Total phosphorus (Ptot) in bulk deposition varied between 2 µg L^{-1} and 9 µg L^{-1} with the highest values at SE04 Gårdsjön with influence of sea deposition. In stream water, however, Ptot was highest at SE14 Aneboda with 37 µg L^{-1} also having the highest DOC concentrations. The other sites had average Ptot concentrations between 3 µg L^{-1} and 12 µg L^{-1} with SE16 Gammtratten being highest.

Inorganic aluminum (Al_i), toxic to fish and other gill-breathing organisms, has been analyzed in soil solution, groundwater and surface waters at the IM sites. Relatively high total Al concentrations occurred in the soil solution (0.4–2.1 mg L^{-1}) as well as in stream water (0.54–0.59 mg L^{-1}) at the southern sites Aneboda and Kindla with low pH (4.7–4.8). At the northern site SE16 with a pH of 5.6, the total Al concentrations were low, approximately 0.24 mg L^{-1}. Inorganic Al made up 17–43% of the total Al at the three sites (data from 2015 lacking for Gårdsjön), corresponding to 0.04–0.23 mg Al_i L^{-1} with high Al_i at low pH, and the 0.04 mg Al_i L^{-1} at the northern site Gammtratten with higher pH. According to the SEPA classification system, the Al_i concentrations at Aneboda and Kindla are considered extremely high, and high at Gammtratten. The priority heavy metals Pb, Cd and Hg were still accumulating in the catchment soils, while the stream concentrations were low compared with the levels causing biological effects. However, methyl mercury, only measured at Aneboda, was still relatively high creating prerequisites for bioaccumulation.

In summary, the four Swedish IM sites show low ion contents and permanently acidic conditions. In stream water, only the northern site SE16 Gammtratten had buffering capacity related to bicarbonate alkalinity. Organic matter has an impact on the water quality with respect to colour, metal complexation, and phosphorus concentrations at all sites, but less at SE15 Kindla, where rapid soil water flow paths provide low DOC and acidic waters. For SE14 Aneboda the forest dieback provides a relatively high share of water runoff as well as high nitrate concentrations compared with the other three sites. SE04 Gårdsjön is strongly influenced by the sea.

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Annex 4

The state of geoecosystems in Poland in the year 2016 based on IMNE program

Report on National ICP IM activities in Poland

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Introduction

The aim of the Integrated Monitoring of Natural Environment (IMNE), as a sub-system of Governmental Environment Monitoring (Kostrzewski et al. 1995), is the submission of data and based on that determination of the present state, tendencies of changes, and development of the natural environment of the IMNE catchments, with the use of multi-annual observational-measurement series. Transformations of the natural environment are related i.a. to currently observed climate change and increasing human impact. The results obtained are used to prepare short- and long-term prognoses of the development of the environment, and to present directions of hazards and protection forms. Integrated Monitoring of Natural Environment, in contrary to other professional programs, is providing complex information, not only in frames of realized measurement programs, but most of all is broadening the state of recognition of casual relationships on the state, transformations and development of geographical environment of selected geoecosystems of Poland (Kostrzewski et al. 2013). IMNE methodology is subordinated complex conceptualization of natural environment functioning, throughout the determination of energy and matter balance in river or lake catchment (Kostrzewski 1995).

River or lake catchments are basic obbjects in IMNE research, within which test fields, representative for investigated landscapes are located (Kostrzewski 1995).

Basic aim of this paper is to present synthhesis of the information on the state and development tendencies of selected geoecosystems of Poland in 2016, based on data from period 1994-2015. In annual reports of base stations, information on the state of investigated geoecosystems, kinds of threats for natural environment functioning, and propositions of activities that will allow to keep natural resources, are given.

Elaboration is done with the use of meritorious reports from the hydrological year 2016 (from November 1, 2015 to October 31, 2016), related to the functioning of geoecosystems (catchments) representative in selected landscape zones of Poland. The Integrated Monitoring of Natural Environment research-measurement program was performed on 11 base stations: Wolin, Storkowo, Puszcza Borecka, Wigry, Koniczynka, Różany Strumień, Kampinos, Święty Krzyż, Roztocze, Szymbark, and Karkonosze. For the Base Station Karkonosze results are restricted to the period from January 1 to October 31, 2016. Detailed meritorious presentation of the state of the natural environment in investigated IMNE catchments, is described in IMNE base stations reports concerning 2016 (Bochenek et al. 2017, Jóźwiak et al. 2017, Kejna et al. 2017, Szpikowski et al. 2017, Krakowski et al. 2017, Krzysztofiak et al. 2017, Major et al. 2017, Olszewski et al. 2017, Skotak et al. 2017, Stachyra et al. 2017, Tylkowski et al. 2017). In the elaboration, monitoring data gathered in Central IMNE Data Base for years 1994-2016, were also used.

Geoindicators presented in the following elaboration are related to qualitative and quantitative properties of water circulation in monitored catchments. Qualitative and quantitative characteristics of atmospheric water supply to the catchment, circulating water and discharge legitimate the rule, that water circulation, together with dissolved matter are main factor of natural environmental changes in the temperate morphoclimatic zone. This is why IMNE research programs are adapted to the regularity that water circulation is of biggest importance for the functioning of geographical environment of Polish geoecosystems (Kostrzewski 2003). Water circulation is deciding about natural environmental changes in the investigated catchments, despite their location in the landscape structure of Poland.

Current IMNE information and data bank allow to asses the state of the environment and prognosis of its development. Central IMNE Data Base holds over 1.3 million records of data from the period 1994-2016.

IMNE research catchments

Basic object of research in IMNE base stations are river or lake catchments, representative for a particular geographical region. In the catchment and its surrounding test fields and measurement sites are located. During the year 2016 complementary terrain investigations and laboratory analytics, according to standardized methods were performed on 11 IMNE stations (Fig. 1, Tables 1,2).

Location of IMNE base stations in Poland is taking into consideration the differentiation of landscape zones in Poland (Mizgajski & Stępniewska 2012, Kostrzewski et al. 2014) and meso-regions in relation to dominant landforms and terrain coverage (Łowicki & Mizgajski 2013) (Fig. 1, Table 1).

Figure 1. Location of IMNE stations in landscape zones of Poland (changed, after Kostrzewski et al. 2014).

Table 1. Characteristics of the location of IMNE representative catchments in landscape-ecological zones and according to dominant terrain cover form (changed, after Kostrzewski et al. 2014).

IMNE station	Catchment	Landscape zone	Dominant form of land coverage
Wolin	Jezioro Gardno	Baltic Sea	Distinctly forested, moderatly natural
Storkowo	Parsęta	Lakelands	diversified
Puszcza Borecka	Jezioro Łękuk	Lakelands	diversified
Wigry	Czarna Hańcza	Lakelands	Distinctly agricultural
Koniczynka	Struga Toruńska	Lakelands	Distinctly agricultural
Różany Strumień	Różany Strumień	Lakelands	Distinctly unnatural, agricultural
Kampinos	Olszowiecki Kanał	Lowlands	Distinctly unnatural, moderately forested
Święty Krzyż	Wieniec	Uplands	Distinctly agricultural, moderately unnatural
Roztocze	Świerszcz	Uplands	Distinctly forested
Szymbark	Bystrzanka	Mid-mountains	Distinctly agricultural, moderately unnatural
Karkonosze	Wrzosówka	Mid-mountains	Distinctly forested

The location of IMNE base stations takes into consideration the differentiation of the country landscape structure, and selected research catchments are treated as representative for particular geographical region (Table 2).

Table 2. Physical-geographical characteristics of IMNE representative catchments in 2016.

Catchment	Catchment area [km^2]	Catchment/basin	Physical-geographical mesoregion	Physical-geographical macroregion
Jez. Gardno	2,4	Morze Bałtyckie	Uznam i Wolin	Pobrzeże Szczecińskie
Parsęta	74,4	Parsęta	Pojezierze Drawskie	Pojezierze Zachodniopomorskie
Jez. Łękuk	13,3	Węgorapa/Pregoła	Kraina Wielkich Jezior	Pojezierze Mazurskie
Czarna Hańcza	7,4	Niemen	Równina Augustowska	Pojezierze Litewskie
Struga Toruńska	35,2	Wisła	Pojezierze Chełmińskie	Pojezierze Chełmińsko-Dobrzyńskie
Różany Strumień	7,7	Warta/Odra	Pojezierze Poznańskie/ Poznański Przełom Warty	Pojezierze Wielkopolskie
Kanał Olszowiecki	20,2	Łasica/Wisła	Kotlina Warszawska	Nizina Środkowo-Mazowiecka
Wieniec	1,3	Kamienna/Wisła	Góry Świętokrzyskie	Wyżyna Kielecko-Sandomierska
Świerszcz	46,5	Wieprz/Wisła	Roztocze Zachodnie/ Roztocze Środkowe	Roztocze
Bystrzanka	13,0	Ropa/Wisła	Beskid Niski / Pogórze Ciężkowickie Doły Jasielsko-Sanockie	Beskidy Środkowe/ Pogórze Środkowobeskidzkie
Wrzosówka	11,5	Kamienna/Odra	Karkonosze	Sudety Zachodnie

IMNE research catchments and the areas naturally especially important, national parks and "Natura 2000"

Six IMNE catchments are located in national parks: Woliński, Wigierski, Kampinoski, Świętokrzyski, Roztoczański and Karkonoski (Fig.2). Nine out of IMNE research catchments are included in the "Natura 2000" network (Fig. 3)

Figure 2. Location of IMNE base stations in Polish national parks.

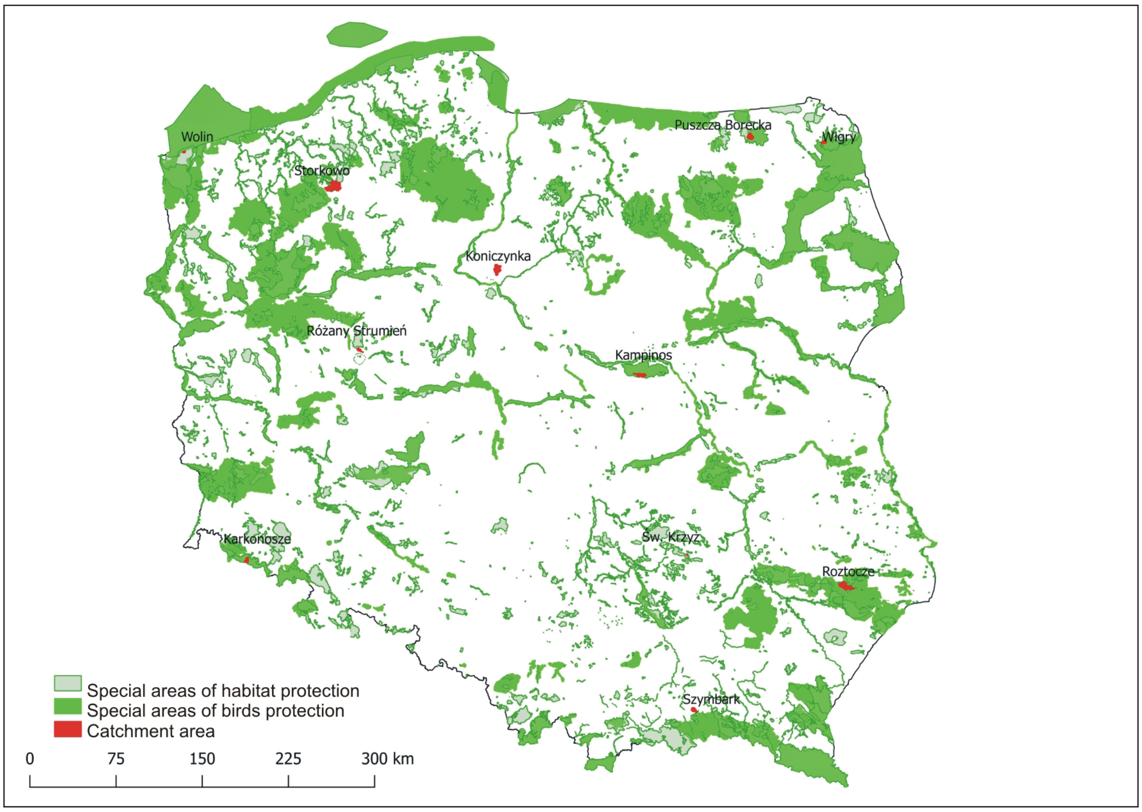

Figure 3. Location of IMNE base stations on the frame of "Natura 2000" areas.

Research-measurement program of IMNE base stations

During the year 2016 IMNE base stations realized full range of IMNE measurement programs (Table 3). Some programs were realized together with external units, i.e. program of air pollution with regional environment protection inspectorates (Zachodniopomorskie, Lubelskie).

The state of geoecosystems in Poland in the year 2016

Year 2016 was characterized by relatively small spatial differences in average annual air temperature and annual sum of precipitation (Table 4).

Thermal conditions were unfavorable, because in all investigated catchments 2016 was warmer than normal. Precipitation conditions changed from most favorable in the north (humid year - Storkowo, Wigry and Puszcza Borecka) to neutral in central and southern Poland (normal year in Koniczynka, Kampinos, Święty Krzyż and Roztocze). Quantitative classification of precipitation in 2016 indicates relative spatial uniformity, which is not usual for Polish climate. The situation shows, that precipitation dynamics were influenced by global factors, and regional and local ones were of secondary importance.

The functioning of natural environment was affected by the pollution load from wet atmospheric deposition. During the year 2016 mineralization of precipitation within all catchments, was most unified in the entire research period (Fig. 4).

Precipitation quality in 2016, in terms of SEC and pH, was very good. On none of the stations mineralization of precipitation in 2016 was worse than in the previous year. On three stations (Kampinos, Szymbark and especially Wigry) SEC classification improved compared to 2015. In 2016 pH in recipitation was at similar level as previously. In seven cases precipitation was classified as normal, in four cases in neighboring classes: slightly lowered or slightly raised. It is worth to underline that positive tendency of stabilization or lowering of precipitation occurred in majority of investigated catchments, especially in Wigry and Kampinos. Relatively higher amount of precipitation in 2016 influenced their good quality. In 2016 the higher role of nitrogen oxide than of sulfur dioxide in acidification of precipitation was confirmed (Figure 5).

Table 3. Basic research program realized by IMNE base stations in 2016.

IMNE program/ Base station	Wolin	Storkowo	Puszcza Borecka	Wigry	Koniczynka	Różany Strumień	Kampinos	Święty Krzyż	Roztocze	Szymbark	Karkonosze
meteorology	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations
air pollution	Realized in cooperation	Realized in cooperation	Realized by Stations	Realized in cooperation	Realized in cooperation	Realized in cooperation	Realized in cooperation	Realized in cooperation	Realized in cooperation	Realized in cooperation	Realized in cooperation
precipitation chemistry	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations
throughfall chemistry	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Not executed - no component	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations
stemflow chemistry	Realized by Stations	Not executed - no component	Realized by Stations	Not executed - no component	Not executed - no component	Not executed - no component	Not executed - no component	Realized by Stations	Realized by Stations	Realized by Stations	Not executed - no component
soil sollution chemistry	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Not executed - damage
groundwater	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations
organic delivery	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations
surface water - rivers	Realized by Stations	Realized by Stations	Not executed - no component	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations
surface water - lakes	Realized by Stations	Realized by Stations	Realized by Stations	Not executed - no component	Realized by Stations	Not executed - no component	Not executed - no component	Not executed - no component	Not executed - no component	Not executed - no component	Not executed - no component
structure and dynamics of plant cover	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations
plants invasive species of foreign origin	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations
trees and forests damage	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations
arboreal epiphytes	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations	Realized by Stations

Realized by Stations	Not executed - no component of geographic environment
Realized in cooperation with specialist teams, e.g. Regional Inspectorate for Environmental Protection, Institute for Environmental Protection	Not executed - damage, lack of equipment or other causes

Table 4. Thermal and precipitation classification for IMNE base stations in 2016.

2016 year	WOLIN	STORKOWO	PUSZCZA BORECKA	WIGRY	KONICZYNKA	RÓŻANY STRUMIEŃ	KAMPINOS	ŚWIĘTY KRZYŻ	ROZTOCZE	SZYMBARK	KARKONOSZE
Thermal classification	very warm	warm	very warm	warm	very warm	very warm	warm	very warm	warm	warm	normal
Precipitation classification	normal	wet	wet	wet	normal	wet	normal	normal	normal	wet	normal

Thermal classification
very warm
warm
slightly warm
normal

Precipitation classification
dry
normal
wet

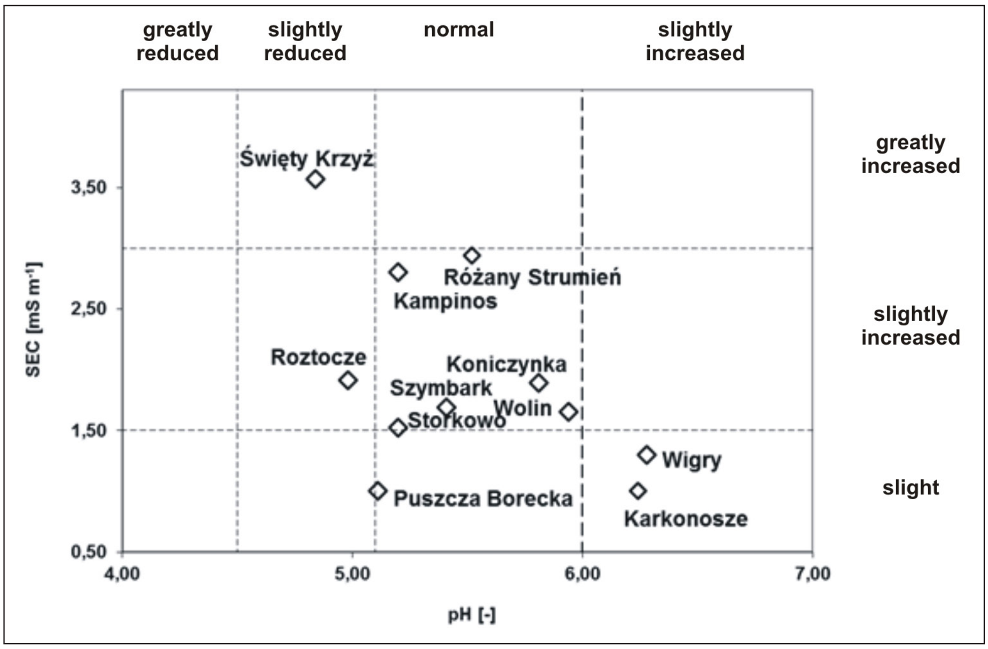

Figure 4. Precipitation pH and SEC classification in IMNE base stations.

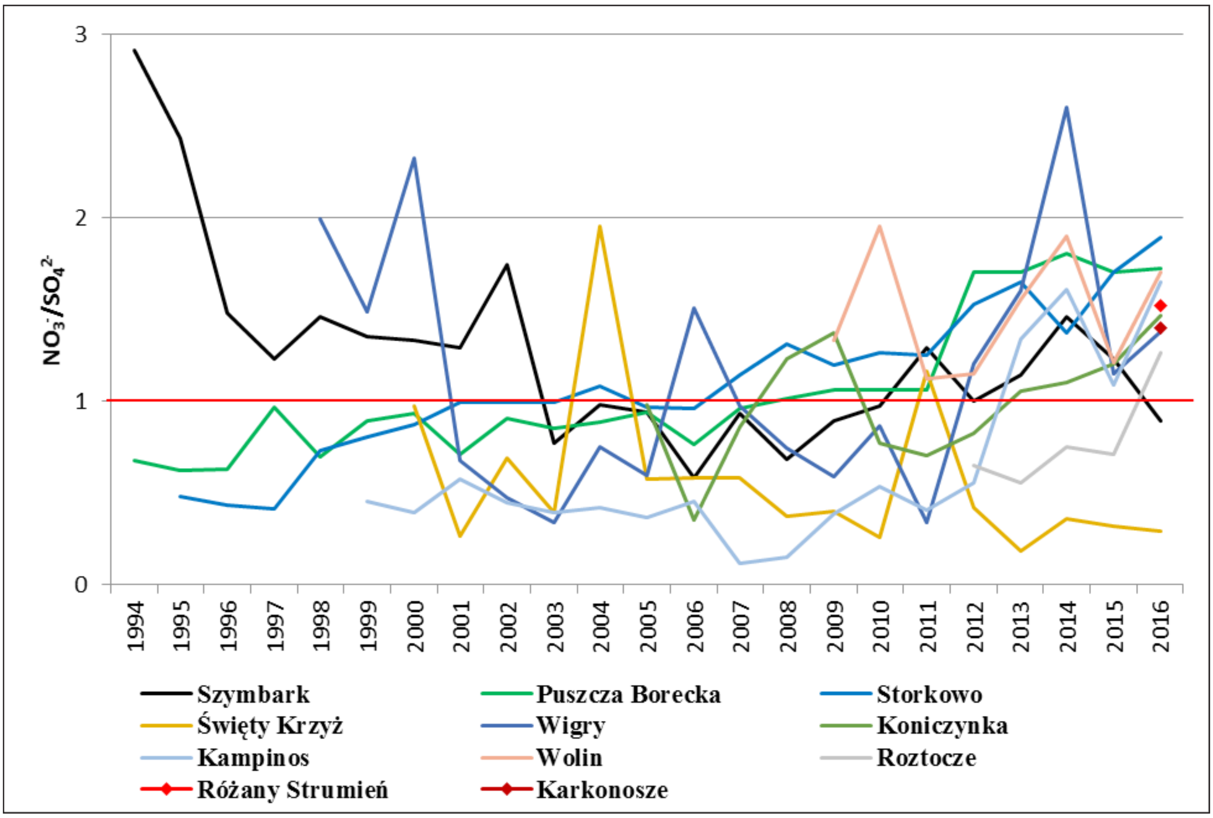

Figure 5. Changes of acidogenic factors index in acidification of precipitation in IMNE base stations.

Good quality of water in IMNE catchments investigated, is indicated by relatively good condition of groundwater, detected in most of investigated aquifers (Table 5).

Based on investigated physical-chemical indexes, it can be stated, that the quality of river water somewhat deteriorated compared to 2015 (Table 6).

Table 5. Chemical class of groundwater in IMNE catchments, according to selected physical-chemical constituents.

IMNE Station	Reactivity	PEW	Ca	Na	Mg	K	PO4	HCO3	Cl	SO4	NO3	NH4	Chemical stage
	[pH]	[mS/m]	mg/l										
Wolin	I	I	II	I	I	I	IV	I	I	I	I	IV	Week
Storkowo	I	I	II	I	I	I	I	I	I	I	III	I	Good
Puszcza Borecka	I	II	III	I	I	I	I	III	I	I	I	I	Good
Wigry	I	I	II	I	I	I	-	II	I	I	I	I	Good
Koniczynka	III	I	I	I	I	I	I	II	I	I	I	IV	Week
Różany Strumień	I	II	III	I	I	I	I	II	II	II	I	I	Good
Kampinos	I	II	III	I	I	II	-	III	I	I	I	I	Good
Święty Krzyż	IV	I	I	I	I	I	I	I	I	I	I	II	Good
Roztocze	IV	I	I	I	I	I	I	I	I	I	I	I	Good
Szymbark	I	I	II	I	I	I	I	II	I	I	II	I	Good
Karkonosze	IV	I	I	I	I	I	I	I	I	I	I	I	Good

Table 6. Average concentration of dissolved substances in riverine water in IMNE catchments in 2016.

Station (catchment)	Landscape zone	S-SO4	N-NO3	N-NH4	Cl	Na	K	Mg	Ca	HCO3	SEC	pH
		mg dm^{-3}									mS m^{-1}	-
Wolin (Lewińska Struga)	Coastal	6.32	0.35	0.28	12.76	10.7	2.31	5.94	50.98	159.36	33.79	8.25
Storkowo (Parsęta)	Lakeland	12.54	1.39	0.2	7.42	6.2	2.12	6.22	81.85	225.79	41.9	8.08
Wigry (Czarna Hańcza)		8.9	1.5	0.2	25.5	24.8	5.1	14,00	79.7	287.6	51.6	8.1
Koniczynka (Struga Toruńska)		41,00	6.92	0.2	43.2	15.9	10,00	18.6	151,00	355,00	80.4	7.9
Różany Strumień (Różany Strumień)		29.36	2.12	0.02	82.08	40.77	4.92	13.85	136.3	342.66	94.55	7.91
Kampinos (Kanał Olszowiecki)	Lowland	25.5	0.35	0.31	23.19	11.1	0.93	13.62	130.16	280.56	68.11	7.25
Święty Krzyż (Wieniec)	Upland	66.54	5.34	0.58	12.74	8.63	1.12	5.86	24.98	15.45	17.58	5.62
Roztocze (Świerszcz)		7.29	0.38	0.19	3.31	2.31	0.97	1.51	52.36	146.22	28.74	7.78
Szymbark (Bystrzanka)	Mid-mountains	2.88	0.31	0.05	5.31	10.8	5.36	5,00	36.7	147.2	21.5	7.64
Karkonosze (Wrzosówka)		3.19	0.43	0.1	7.25	5.18	0.5	1.15	4.16	8.26	5.8	6.17

More than half of the investigated streams in 2016 had good quality, very good (3 mountain streams:Wrzosówka, Wieniec and Bystrzanka) and good (3 streams: Lewińska struga, upper Parsęta and Świerszcz). Other streams had quality lower than good (III-IV class).

In surface and groundwater the tendency to lower concentrations of nitrogen was not detected, which can mean that they have a potential danger for increased eutrophication. Preventional activity may be in such cases implemented by keeping up natural plant coverage next to rivers and lake zones, within which the process of biogens reduction can occur. Multiannual qualitative and quantitative studies of water in rivers and lakes of IMNE catchments confirm decreasing sulfate concentrations. This is mostly connected with the decrease of SO_2 concentration in the air and precipitation. As far back as in 1994-1999 sulfur dioxide concentration was 3 to 5 times higher than in the last period 2007-2016 (Skotak et al. 2016). In the case of NO_2 such tendency did not occur. This confirms the recent bigger role communication has, than that of industrial pollution, in shaping air quality.

Based on 20 year experience in IMNE functioning, it can be stated, that largest influence on the stage, changes and transformations of the natural environment of Polish geoecosystems, are human induced impact of regional (i.e. the supply of atmospheric pollution from outside of the investigated catchments) and local (changes of land use of IMNE catchments) origin (Fig. 6).

Both natural processes (i.e. extreme hydrological and geomorphological events) and human induced processes, connected with atmospheric pollution supply, are hazardous for the functioning of the investigated geoecosystems. In 2016 very important threats for catchments functioning have not been detected. Among natural extreme events transforming natural environment of investigated geoecosystems, 1-2 episodes of meteorological drought in northern Poland, can be mentioned (in the young glacial

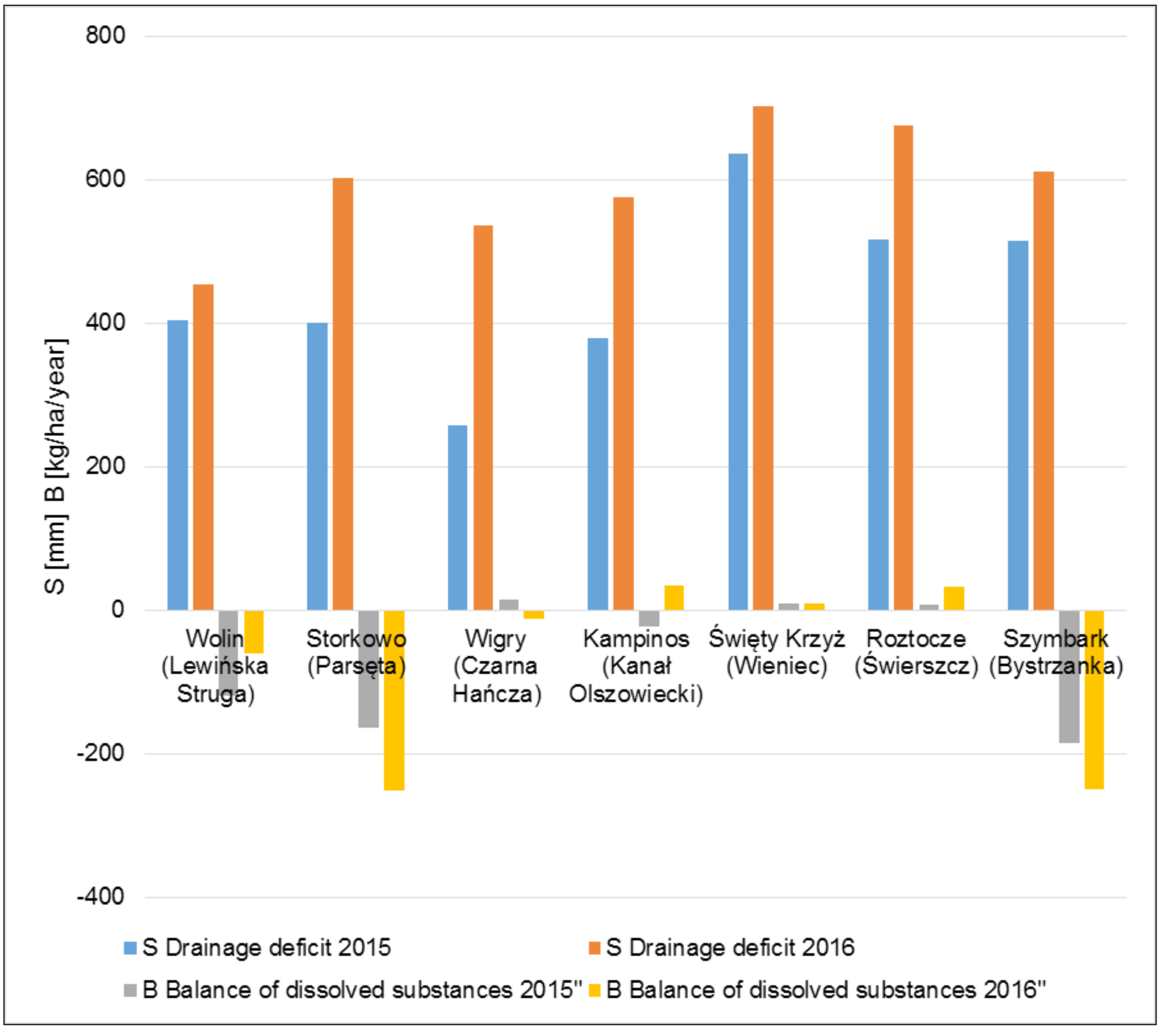

Figure 6. The shortfall of water discharge and dissolved substances balance in IMNE catchments during the years 2015-2016.

zone of Polish Lowlands). However, heat waves (especially sub-urban catchment – Różany Strumień) and rainless periods did not largely influence the functioning of the natural environment. Important issue influencing water circulation in investigated catchments in 2016 ,was the supply of groundwater resources after previous dry year. Despite the fact that 2016 was normal or humid in relation to precipitation amount, no intensive river flows were detected (except Parsęta river).

Very important from the point of view of preservation and assessment of natural resources of Polish geoecosystems, was in 2016 the realization of base stations of biotic programs (structure and dynamics of plants, invasive species) and programs related to human impact (land use changes, assessment of geoecosystem services). The evaluation of natural environment in IMNE catchments allowed to work out methods for other Polish geoecosystems.

Based on IMNE program realized in 2016, the assessment of natural environmental state was performed (Table 7).

The assessment of particular IMNE programs (taking into account qualitative and quantitative aspects and tendencies of the development of natural environment components), allowed to classify catchments to the states: favorable (>5 pts.), neutral (0-5 pts.) and unfavorable (<0 pts.). It is a relative view, only to compare investigated catchments between each other. Relatively best state was characteristic for the stations in northern Poland (in the area of coastal lowlands and lakelands: Wolin, Storkowo, Puszcza Borecka, Wigry) and southern Poland (in the mid-mountains zone:

Table 7. The state of IMNE research catchments in 2016 (1 – favorable; 0 – neutral; -1 – unfavorable).

IMNE program	Wolin	Storkowo	Puszcza Borecka	Wigry	Koniczynka	Różany Strumień	Kampinos	Święty Krzyż	Roztocze	Szymbark	Karkonosze
meteorology	0	1	1	1	0	1	0	0	0	1	1
air pollution	1	1		1	1	-1	1	1	1	1	1
precipitation chemistry	1	1		1	1	1	1	0	1	1	1
throughfall chemistry	1	1		1		1	1	0	1	1	1
stemflow chemistry	1		1					1	1	1	
soil water chemistry	0	1	1	0	-1	1	0	-1	0	1	
groundwater	-1	1	0	0	-1	0	0	0	-1	0	0
organic delivery	0	0	0	0		0	0	0	0	0	0
surface water - rivers	-1	1		-1	-1	-1	-1	0	1	1	1
surface water - lakes	1	1	1		0						
structure and dynamics of plant cover	0	-1	1	1	-1	-1	0	1	1	-1	-1
plants invasive species of foreign origin	1	0	1	0	-1	-1	1	1	-1	1	1
trees and forest damage	1	1	1	0		1	1	0	0	0	1
arboreal epiphytes	0	1	1	0	0	-1	0	0	0	1	1
extreme events	1	1	1	1	0	-1	0	1	0	1	1
changes of land coverage and land use	1	1	1	1	0		0	1	0	0	
ECOLOGICAL STAGE	7	11	10	7	-3	-1	4	4	5	9	8

Szymbark, Karkonosze). Neutral state was characteristic for mid-Polish lowlands (Kampinos) and uplands zone (Święty Krzyż and Roztocze). The worse state was found where intensive human impact is observed due to agriculture (Koniczynka) and influences of urban center (Różany Strumień)

Conclusions

As Central IMNE Database covers over 20 years of measurement series, it is reasonable to construct prognosis of future changes of natural environment in the investigated catchments. In 2017 base station reports will include the prognosis of changes based on modeling of selected natural environmental elements (Soil and Water Assessment Tool – SWAT modeling), e.g. changes in water circulation elements – precipitation, discharge in the context of the transformation of chemical composition of water and acidic compounds ($S\text{-}SO_4$, $N\text{-}NO_3$) migration, biogens (nitrogen and phosphorus). The anticipation of future changes in investigated catchments will relate to uniform time intervals, like 10, 30 or 50 years.

Integrated Monitoring of Natural Environment has a role of scientific monitoring, and in contrary to specialized monitoring, it comprises complex assessment of natural environment based on standardized stationary research in catchments representative for particular landscape zones of Poland. The realization of IMNE program, within the frame of nature monitoring in the Governmental Natural Environment Monitoring, is of great importance for the protection of the natural environment in Poland. Eight out of IMNE research catchments (except Koniczynka, Różany Strumień and Szymbark), are located within areas of special protection Natura 2000, and five are located in national parks. The results of integrated monitoring are useful for national park authorities and help to realize the Natura 2000 program, to save the natural environment heritage of Poland, according to sustainable development rules.

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The Integrated Monitoring Programme (ICP IM) is part of the effect-oriented activities under the 1979 Convention on Long-range Transboundary Air Pollution, which covers the region of the United Nations Economic Commission for Europe (UNECE). The main aim of ICP IM is to provide a framework to observe and understand the complex changes occurring in natural/semi natural ecosystems.

This report summarizes the work carried out by the ICP IM Programme Centre and several collaborating institutes. The emphasis of the report is in the work done during the programme year 2016/2017 including:

- A short summary of previous data assessments
- A status report of the ICP IM activities, content of the IM database, and geographical coverage of the monitoring network
- A report on connections between calculated Critical Load exceedances and observed fluxes and concentrations of nitrogen in runoff
- A report on concentrations of heavy metals in important forest ecosystem compartments
- National Reports on ICP IM activities are presented as annexes.

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